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Assessment of Noise Levels In and Around the Sikorsky S-70A-9 Black Hawk Helicopter

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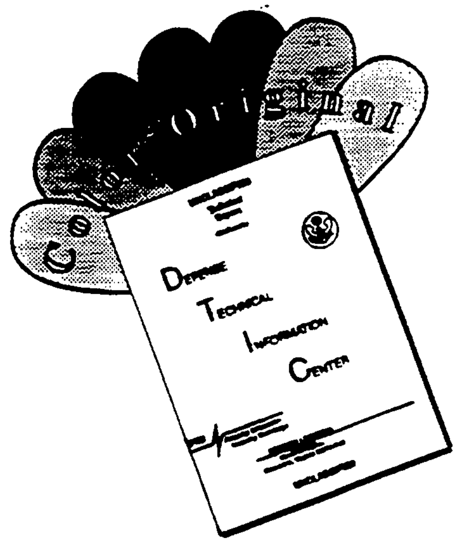

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Air Operations Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

This document reports the results of a comprehensive noise survey of the Sikorsky S-70A-9 Black Hawk helicopter environment and provides an assessment of the hearing protection devices worn by personnel exposed to this environment. Ambient noise levels were measured in the cabin of the Black Hawk at four positions under various flight conditions and at thirteen positions outside the Black Hawk under various ground running conditions. The attenuation properties of the ALPHA helmet, the Roanwell MX-2507 Communications Headset and the EAR earplug were also assessed. Results show that these devices do not always provide enough hearing protection to meet current conservation regulations (DIG PERS 19-4), even when worn in combination. Recommendations relating to the use of these hearing protection devices and the maximum Permissible Daily Exposure Duration (PDED) for personnel exposed to the Black Hawk environment are made.

RELEASE LIMITATION

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EXECUTIVE SUMMARY

The Sikorsky S-70A-9 Black Hawk helicopter provides the Australian Army with a medium lift helicopter capability which fulfills troop and cargo movement roles. However, the Black Hawk, like most modern rotary wing aircraft of its size, is a noisy aircraft and the Directorate of Aviation - Army (DAVN-A) has expressed concern in relation to the noise levels experienced by aircrew, maintenance crew and troops in the Black Hawk environment. This issue has been exacerbated by recent amendments to the Australian Defence Force hearing conservation regulations (DIG PERS 19-4, 1992) which have reduced the Permissible Noise Exposure (PNE) for personnel from 90 dBA to 85 dBA for an 8 hr day.

DAVN-A tasked Air Operations Division to conduct a comprehensive noise analysis of the Black Hawk environment and assess the attenuation properties of the hearing protection devices currently worn by personnel exposed to the Black Hawk environment.

The present paper reports the results of this analysis and provides eight recommendations relating to the use of these hearing protection devices and to the maximum Permissible Daily Exposure Duration (PDED) for personnel exposed to the Black Hawk environment.

1. It is recommended that Pilots and Loadmasters flying in the Black Hawk be provided with additional hearing protection devices in order to meet hearing conservation regulations and maintain reasonable manning levels for operational flying.

2. It is recommended that Pilots and Loadmasters flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the Advanced Lightweight Protective Helmet for Aircrew (ALPHA) in order to meet current hearing conservation regulations and maintain reasonable manning levels for operational flying. However, earplugs may not be the most effective acoustic solution for the Black Hawk noise environment.

3. It is recommended that helmet mountable active noise reduction systems (such as that produced by the UK Defence Research Agency) be assessed for their effectiveness in the Black Hawk acoustic environment.

4. It is recommended that maintenance crew flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the Roanwell MX-2507 Communications Headset in order to reduce exposure to communications traffic with a high sound pressure level.

5. It is recommended that troops flying in the Black Hawk be required to wear earplugs with a sound level conversion rating of 22 or higher (such as the EAR earplug). The earplugs must be fitted properly and adequate instruction to this effect should be included in the standard pre-flight safety briefing.

6. It is recommended that maintenance crew wear earplugs (such as the EAR earplug) in combination with the Roanwell Headset (or an equivalent muff type hearing protection device) any time they are working around the Black Hawk with Auxiliary Power Unit (APU) and/or turbines running with rotors stopped. Maintainers should not work for longer than 1.5 hr per day at positions near the APU exhaust when the APU and turbines are running with rotors stopped, even when wearing earplugs in combination with the headset.

7. It is recommended that aircrew wear earplugs (such as the EAR earplug) in combination with their ALPHA helmet any time they are walking around the Black Hawk with APU and/or turbines running with rotors stopped. When the APU and turbines are running

with rotors stopped, aircrew should not occupy positions near the APU exhaust for longer than 1 hr per day, even when wearing earplugs in combination with the ALPHA helmet.

8. It is recommended that maintenance and aircrew should not occupy positions close to the APU exhaust or at the edge of the rotor sweep when the APU and turbines are running with rotors turning, even when wearing earplugs (such as the EAR earplug) in combination with the ALPHA helmet or Roanwell Headset (or equivalent muff). The practice of holding passengers and support crew at the edge of the rotor sweep prior to approaching the aircraft should be abandoned, or at least modified so that passengers and support crew stand well back from the edge of the rotor sweep. If there is a requirement for maintenance crew or aircrew to occupy a position external to the aircraft when APU and turbines are running with rotors turning, the quietest positions are forward of the main cabin door close to the aircraft skin. Maintenance crew and aircrew should be aware that even at these positions their maximum exposure time is limited to around 2 hr and 30 min per day respectively. If there is any requirement to occupy a position near the APU exhaust or at the edge of the rotor sweep while the APU and turbines are running with rotors turning, the maximum exposure time for maintenance crew and aircrew is in the order of 12 and 2 min per day respectively.

This report will assist the Australian Defence Organisation in avoiding noise-induced hearing damage claims in future years and in maintaining personnel at a better state of fitness for military operations.

GLOSSARY

ALPHA (helmet)	Advanced Lightweight Protective Helmet for Aircrew
ANR	Active Noise Reduction
AOD	Air Operations Division
APU	Auxiliary Power Unit
ARDU	Aircraft Research and Development Unit
DAVN-A	Directorate of Aviation - Army
dB	decibel
dBA	decibel (A-weighted)
dBC	decibel (C-weighted)
DRA	Defence Research Agency
HAMS	Head Acoustic Measurement System
HPD	Hearing Protection Device
ICS	Inter-Communication System
IEC	International Electrotechnical Commission
OASPL	Overall Sound Pressure Level
PDED	Permissible Daily Exposure Duration
PNE	Permissible Noise Exposure
SPL	Sound Pressure Level

1. INTRODUCTION

The Sikorsky S-70A-9 Black Hawk helicopter provides the Australian Army with a medium lift helicopter capability which fulfils troop and cargo movement roles. However, the Black Hawk, like most modern rotary wing aircraft of its size, is a noisy aircraft and the Directorate of Aviation - Army (DAVN-A) has expressed concern in relation to the noise levels experienced by aircrew, maintenance crew and troops in the Black Hawk environment.

All personnel exposed to the Black Hawk noise environment wear some form of hearing protection device. Aircrew wear the Advanced Lightweight Protective Helmet for Aircrew MK IV (ALPHA helmet), maintainers wear a standard communication headset (Roanwell MX-2507) or soft insert earplugs (such as the EAR™ yellow foam earplug[1]), while troops wear soft insert earplugs (EAR earplug). However, given that aircrew, maintenance crew and passengers frequently complain about noise levels in and around the Black Hawk, it is doubtful whether any of these devices provide sufficient attenuation to allow personnel to maintain 'realistic' exposure times. This issue has been exacerbated by recent amendments to the Australian Defence Force hearing conservation regulations, which have reduced the Permissible Noise Exposure (PNE) for personnel from 90 dBA to 85 dBA[2] for an 8 hr day [ref 1].

Given this background, DAVN-A tasked Air Operations Division to conduct a comprehensive noise survey of the Black Hawk environment, assess the attenuation properties of the hearing protection devices worn by personnel exposed to the Black Hawk environment, calculate the at-ear SPLs experienced by these personnel and also provide advice regarding the maximum Permissible Daily Exposure Duration (PDED) for these personnel. These aims were achieved by:

(a) measuring ambient cabin noise levels at four positions in the Black Hawk under various flight conditions and using spectral analysis techniques to determine the acoustic characteristics of this noise;

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[1] The EAR™ earplug is manufactured by the Cabot Safety Corporation, 5457 West 79th Street, Indianapolis, IN 46268, USA.

[2] Several frequency weighting curves (A, B and C) are used in human acoustic measurements to allow for the differential response of the human ear across the whole audio frequency spectrum. The different weighting curves represent the human ear's frequency response at different Sound Pressure Levels (SPLs) — as the SPL of the signal increases, the low frequency response of the ear increases and the appropriate weighting curve moves from A through C. It is appropriate, for example, to report A-weighted levels (dBA) for acoustic signals with low to moderate SPLs and C-weighted levels (dBC) for signals with high SPLs. However, certain conventions regarding the use of weighting curves have been adopted in the evaluation of hearing protection devices. High freefield ambient SPLs are C-weighted, while at-ear SPLs under the protector are A-weighted (even though the at-ear SPL is still high enough to justify the use of the C-weighting curve in many cases). These conventions have been adopted because the Australian Standard [ref 2] requires that Permissible Daily Exposure Durations (PDEDs) be calculated using A-weighted at-ear SPLs, and will be followed in this paper. A and C frequency weightings for $^1/_3$ octave bands are included in Appendix A so the reported $^1/_3$ octave measurements can be re-calculated in terms of the other frequency weighting curve if so desired.

(b) measuring ambient noise levels at thirteen positions outside the Black Hawk under various ground running conditions and using spectral analysis techniques to determine the acoustic characteristics of this noise;

(c) measuring the attenuation properties of the ALPHA helmet, the EAR earplug and the Roanwell MX-2507 Communications Headset and using spectral analysis techniques to determine the acoustic characteristics of these attenuation devices;

(d) using the measurements described in (a), (b) and (c) above to calculate the at-ear SPLs experienced by personnel wearing the different hearing protection devices in the Black Hawk environment.

2. EQUIPMENT AND EXPERIMENTAL PROCEDURE

2.1 Aircraft

The S-70A-9 Black Hawk's primary mission is tactical troop movement. In this role it is operated by a crew of four consisting of two Pilots and two Loadmasters. The Pilots occupy the front starboard and port seats in the aircraft while the Loadmasters occupy seats situated directly behind the Pilots. The cabin is configured with another ten seats. These seats are arranged in two parallel rows of five along the centre line of the aircraft (see Figure 1).

In-flight measurements were made aboard a Black Hawk on flights from the Aircraft Research and Development Unit (ARDU) at RAAF Edinburgh. All in-flight measurements were made at an altitude of approximately 1000 ft above sea-level.

Ground running measurements were made on the tarmac at RAAF Edinburgh using the same aircraft.

2.2 Recording and Analysis Equipment

Noise levels were recorded using the Head Acoustic Measurement System (HAMS; see Figure 2). The HAMS is a dummy head device that has been specifically designed for noise measurement and meets IEC 711 standards for coupled measurements (ie, measurements where the ear canal is coupled to a headset or helmet [ref 3]). The HAMS consists of a dummy head, ear canal simulators and a 'torso box' containing equalization and recording equipment.[3] Left and right outputs from microphones in the ear canal simulators are equalized and passed to a digital audio tape recorder with a sampling frequency of 44.1 kHz. The microphones have linear properties and a frequency response that is effectively flat between 20 Hz and 20 kHz (± 1 dB). Each channel was calibrated using a Bruel and Kjaer 4230 sound level calibrator.

Recordings were analysed using a Hewlett-Packard 3567A dual channel spectral analyser. Third-octave band analyses were performed [ref 2] to determine the acoustic characteristics of:

(a) internal cabin noise during flight in the Black Hawk;

(b) external noise radiated around the Black Hawk during ground running;

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[3] The HAMS represents a considerable advance over traditional acoustic measurement and recording devices such as stand-alone microphones and sound level meters because it incorporates the representative acoustic transfer characteristics of the human head and torso when measuring the acoustic environment [ref 4].

(c) the attenuation properties of the ALPHA helmet, the EAR earplug and the standard communications headset (Roanwell MX-2507).

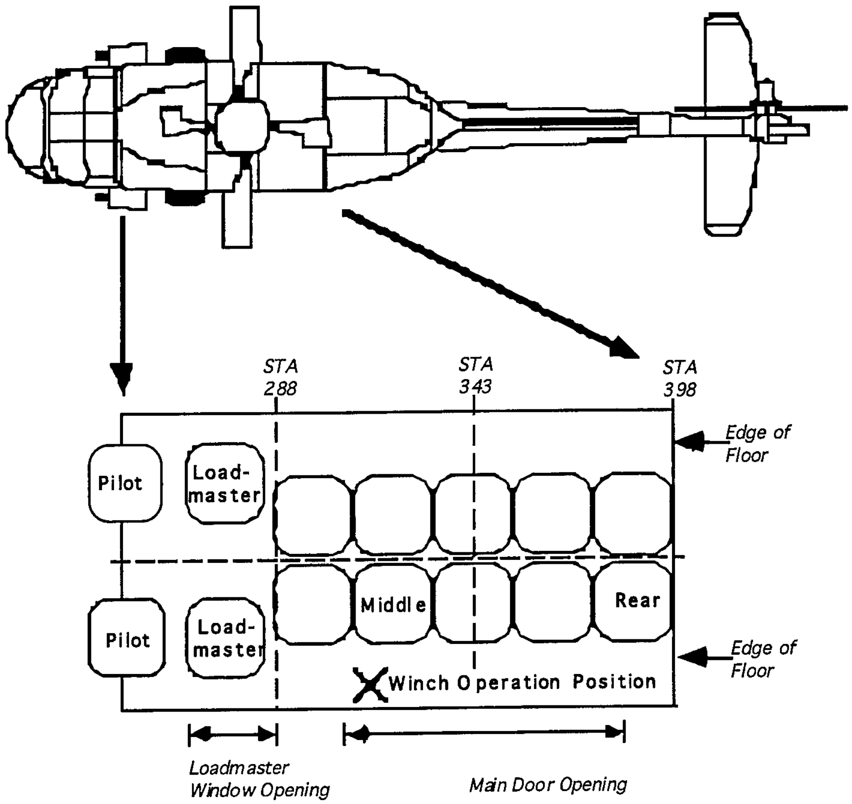


Figure 1. Seating positions in the S-70A-9 Black Hawk. Measurements were made at the Pilot, Loadmaster, Middle, Rear and Winch Operation positions on the port side of the aircraft.

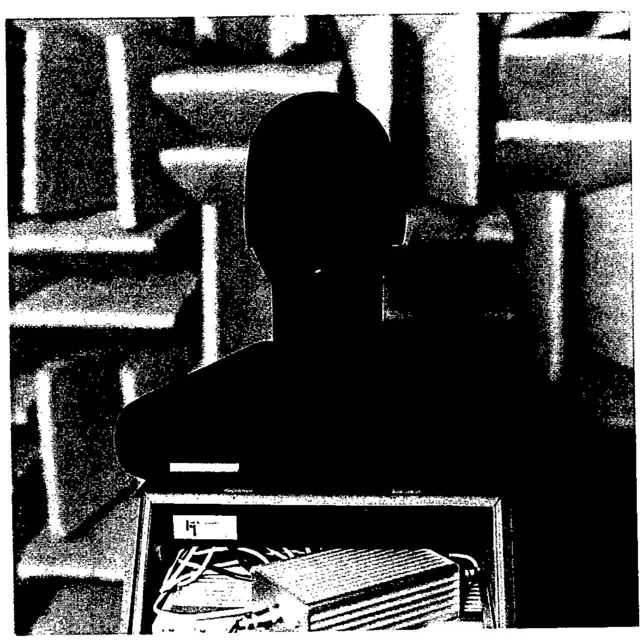


Figure 2. The Head Acoustic Measurement System.

2.3 Measurement Positions and Conditions

2.3.1 Internal Noise Measurements During Flight

It was necessary to restrict the number of internal measurement positions as the flight time available for the trials was limited. Preliminary investigation with a Bruel and Kjaer type 2209 sound level meter indicated that sound pressure levels (SPLs) in the port side of the cabin were marginally greater than those on the starboard due to noise generated by the Auxiliary Power Unit (APU) which is located on the port side of the aircraft. In order to determine the 'worst case scenario', measurements were made on the port side of the aircraft with the Pilot, Loadmaster, Middle and Rear seats chosen as representative positions (see Figure 2). The HAMS was strapped into the seat at each position while recordings were made.

Measurements were made for the following flight conditions and configurations:

(a) transition (hover to cruise), with main door closed and Loadmaster windows (i) open and (ii) closed;

(b) cruise (125 kn), with main door closed and Loadmaster windows (i) open and (ii) closed;

(c) deceleration (cruise to hover), with main door closed and Loadmaster windows (i) open and (ii) closed;

(d) hover, with main door closed and Loadmaster windows (i) open and (ii) closed;

(e) hover, with main door open and Loadmaster windows (i) open, and (ii) closed.

Two measurements were also made with the HAMS placed on the floor of the aircraft in the 'Winch Operation' position (ie, the approximate position where the Loadmaster would kneel when conducting winching operations — although the winch is actually located on the starboard side of the aircraft). These two measurements were made for the following conditions:

(f) hover, with main door open and Loadmaster windows (i) open, and (ii) closed.

2.3.2 External Noise Measurements During Ground Running

Preliminary investigation with a Bruel and Kjaer type 2209 sound level meter indicated that SPLs on the port side of the aircraft were also marginally greater than those on the starboard in all ground running conditions. This was particularly the case at the rear of the aircraft, near the APU exhaust. Accordingly, ground running measurements were also made on the port side of the aircraft in order to determine the 'worst case scenario'.

The HAMS was positioned at seven azimuth locations on the port side of the aircraft from directly in front to directly behind in 30° increments (see Figure 3). At each azimuth location the HAMS was positioned at two distances, approximately 0.5 m from the aircraft skin and 8 m from the rotor hub (just outside the rotor tip path), with the exception of position 7 where the measurement was taken 3 m behind the tail rotor. These positions were chosen as representative of the typical positions that maintenance staff would occupy relative to the aircraft (ie, either just outside the rotor tip path or 'against' the aircraft while performing work

on the external airframe). The HAMS was turned to face the rotor hub at each location and measurements were made with:

(a) APU running;

(b) APU running and both turbines at ground idle with rotors stopped;

(c) APU running and both turbines at ground idle with rotors turning at 100% Nr and zero pitch.

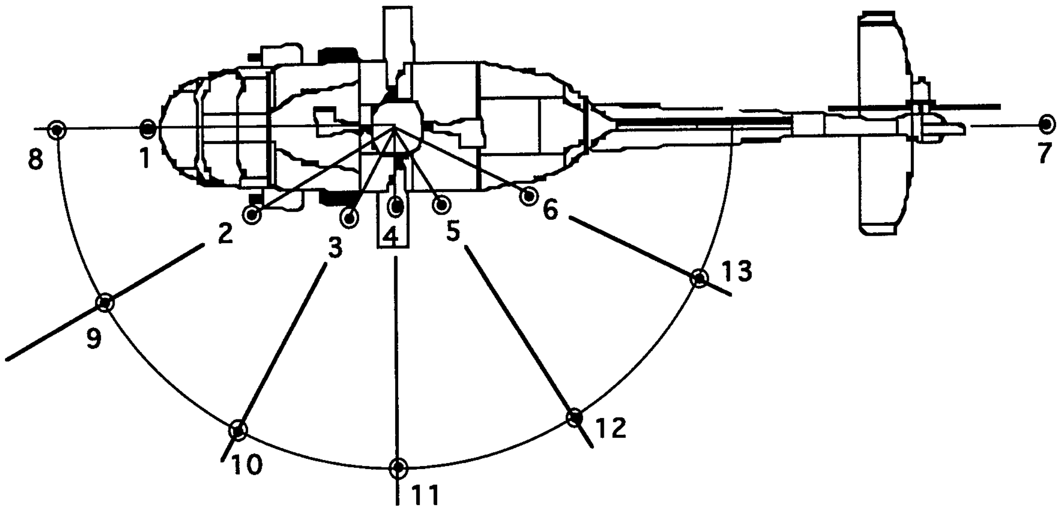


Figure 3. Azimuth locations for ground running measurements.

Care was taken to ensure that the data were not contaminated by noise from any other aircraft operating in the area.

2.4 Measuring the Attenuation Properties of the ALPHA Helmet, EAR Earplug and the Roanwell MX-2507 Communications Headset

Third-octave band analyses were performed in order to determine the attenuation characteristics of the various hearing protection devices (HPDs) [ref 2]. Attenuation was defined as the difference between (a) SPLs measured in each $^1/_3$ octave band with the 'bare' head, and (b) SPLs measured in each $^1/_3$ octave band with the HPD fitted in a constant flight condition (cruise flight). Measurements were repeated four times for each HPD (with the HPD being removed and refitted to the head for each measurement) and the mean attenuation in each $^1/_3$ octave band minus one standard deviation was reported. This correction conservatively adjusts the attenuation factor to ensure that the reported degree of noise reduction is obtained on 80% of occasions [ref 2].

2.5 Calculating At-Ear SPLs

The at-ear SPLs experienced by personnel wearing the different HPDs in the S-70A-9 Black Hawk environment were calculated by subtracting the corrected attenuation provided in each $^1/_3$ octave band by the HPD from the SPL measured in each $^1/_3$ octave band with the 'bare' head for each measurement condition. The resultant $^1/_3$ octave spectra were A-weighted and integrated across bands to provide an Overall SPL (OASPL) at-ear.

3. RESULTS

3.1 Ambient Levels and Acoustic Characteristics of Cabin Noise During Flight

Table 1 shows the ambient cabin SPLs (dBC re 20 μPa) measured at each position in each flight condition. Also shown is the ambient SPL measured at the 'Winch Operation' position in the Hover, Main Door Open flight condition. The highest SPL for each position is reported, whether measured in the head's left or right ear, in order to determine the 'worst case scenario'. As Table 1 shows, high ambient noise levels were measured at all positions in the cabin of the Black Hawk under normal flight conditions, with levels at the Loadmaster, Middle and Rear positions being generally higher (around 107 dBC) than those measured at the Pilot position (around 104 dBC)

Table 1. Ambient cabin sound pressure levels (dBC re 20 μPa) measured at each position in each flight condition.

	Main Door Open		Main Door Shut	
	LM Wndw Open	**LM Wndw Shut**	**LM Wndw Open**	**LM Wndw Shut**
Hover	**Pilot:** 102 dBC **LM:** 107 dBC **Mid:** 110 dBC **Rear:** 107 dBC **Winch:** 107 dBC	**Pilot:** 101 dBC **LM:** 105 dBC **Mid:** 110 dBC **Rear:** 108 dBC **Winch:** 107 dBC	**Pilot:** 103 dBC **LM:** 107 dBC **Mid:** 107 dBC **Rear:** 106 dBC	**Pilot:** 102 dBC **LM:** 105 dBC **Mid:** 107 dBC **Rear:** 107 dBC
Transition	—	—	**Pilot:** 103 dBC **LM:** 107 dBC **Mid:** 107 dBC **Rear:** 107 dBC	**Pilot:** 102 dBC **LM:** 106 dBC **Mid:** 105 dBC **Rear:** 106 dBC
Cruise	—	—	**Pilot:** 104 dBC **LM:** 107 dBC **Mid:** 107 dBC **Rear:** 107 dBC	**Pilot:** 106 dBC **LM:** 104 dBC **Mid:** 105 dBC **Rear:** 105 dBC
Deceleration	—	—	**Pilot:** 105 dBC **LM:** 110dBC **Mid:** 106 dBC **Rear:** 109 dBC	**Pilot:** 100 dBC **LM:** 104 dBC **Mid:** 105 dBC **Rear:** 109 dBC

Third-octave band analyses were performed on the recordings in order to determine the acoustic characteristics of the cabin noise in the Black Hawk [ref 2]. Figures 4, 5, 6 and 7 show 1/3 octave analyses of the cabin noise measured at the Pilot, Loadmaster, Middle and Rear positions in each flight condition when the Loadmaster windows were open. Analyses of the cabin noise measured at these positions when the Loadmaster windows were shut are not markedly different and are included in Appendix B.

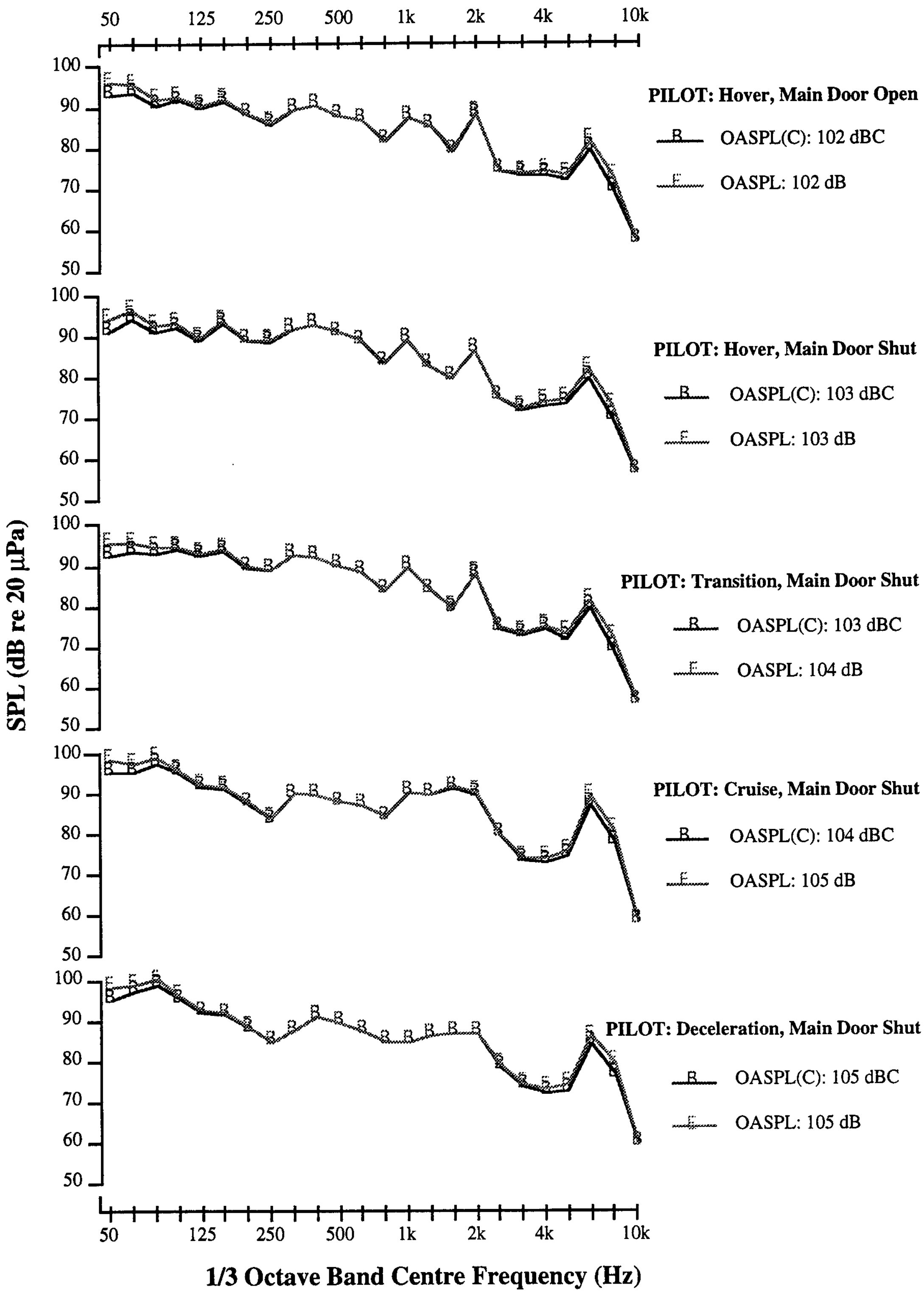


Figure 4. Third-octave analysis of the cabin noise measured at the Pilot position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were open in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

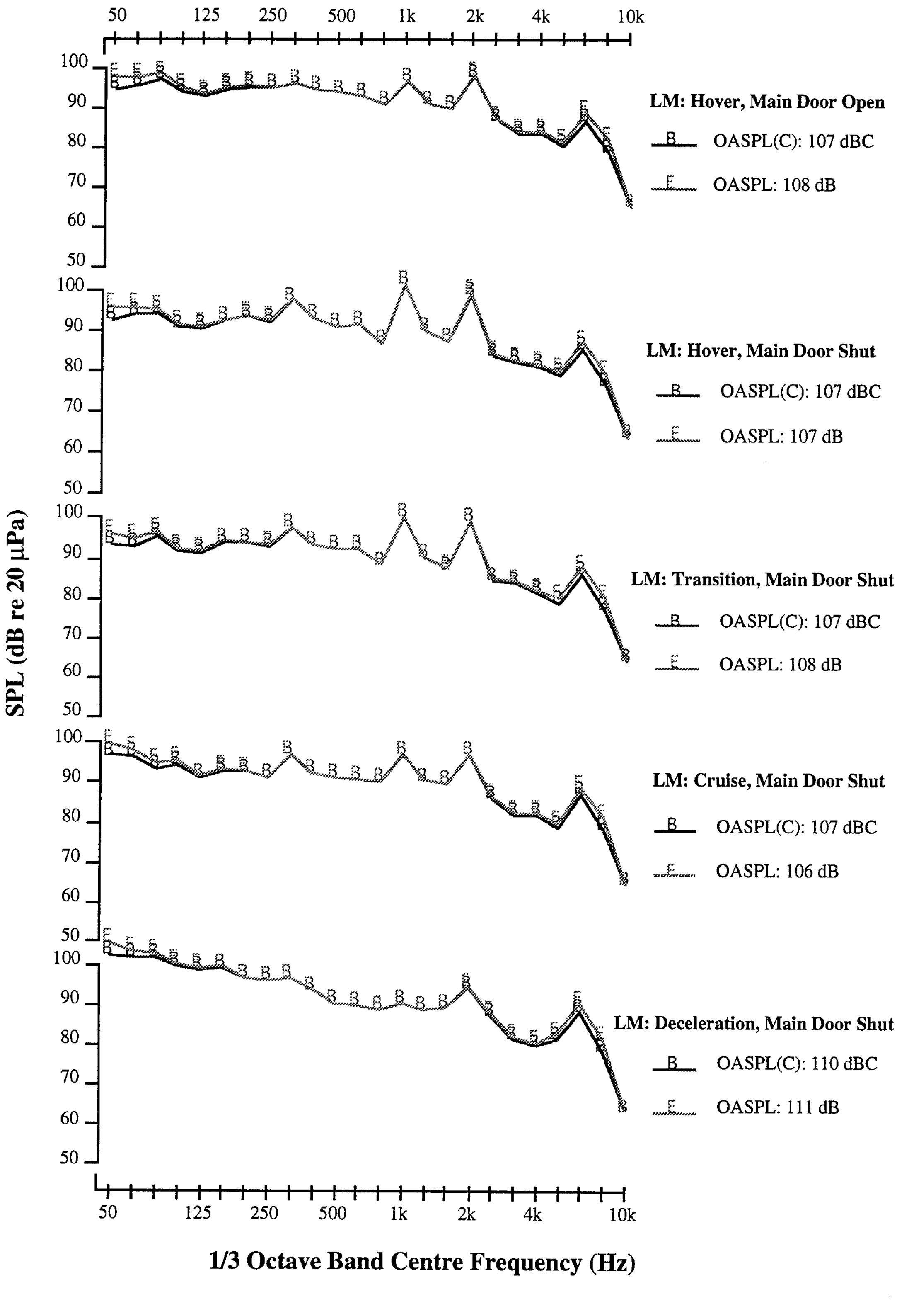


Figure 5. Third-octave analysis of the cabin noise measured at the Loadmaster position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were open in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

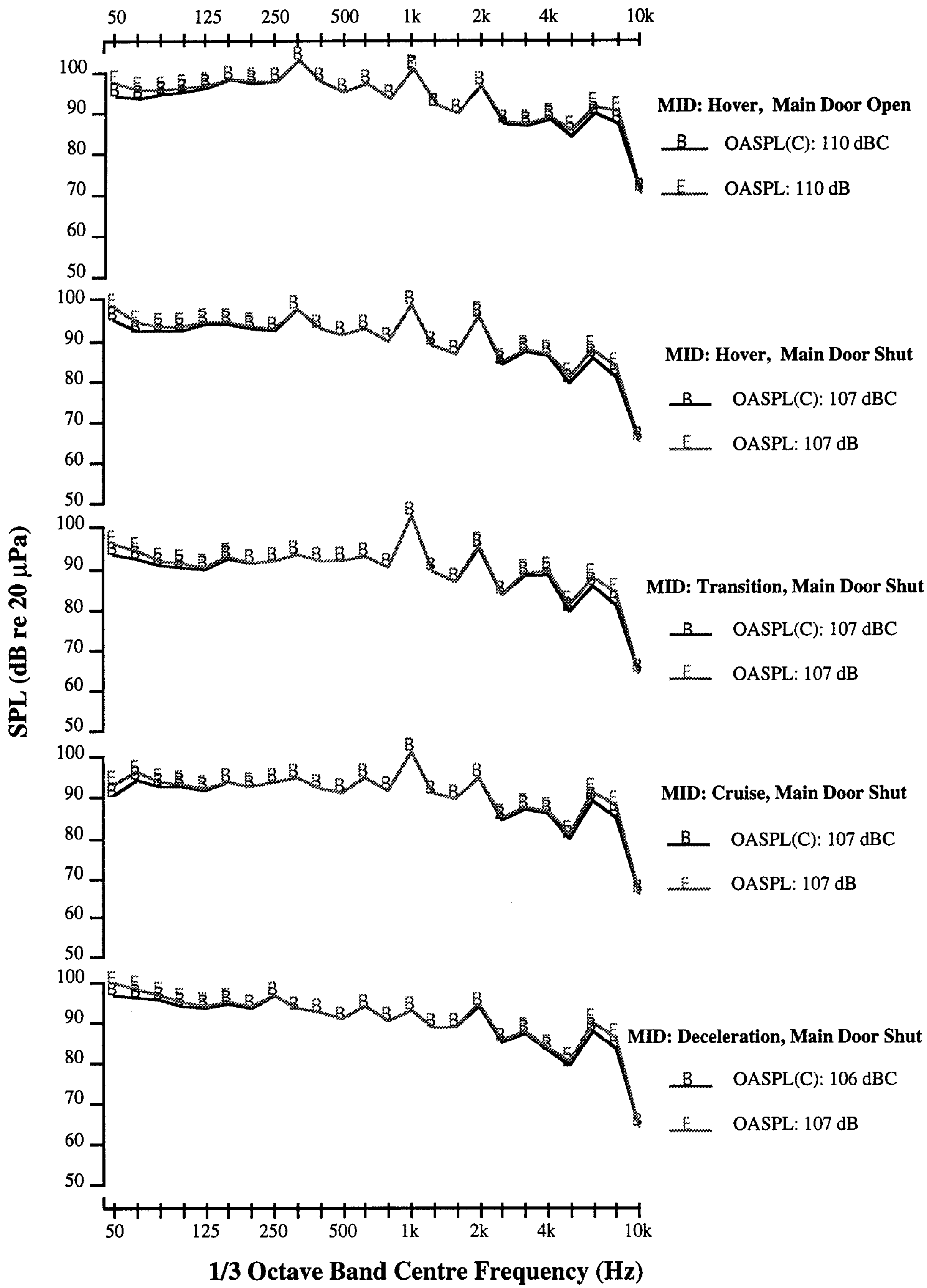


Figure 6. Third-octave analysis of the cabin noise measured at the Middle position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were open in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

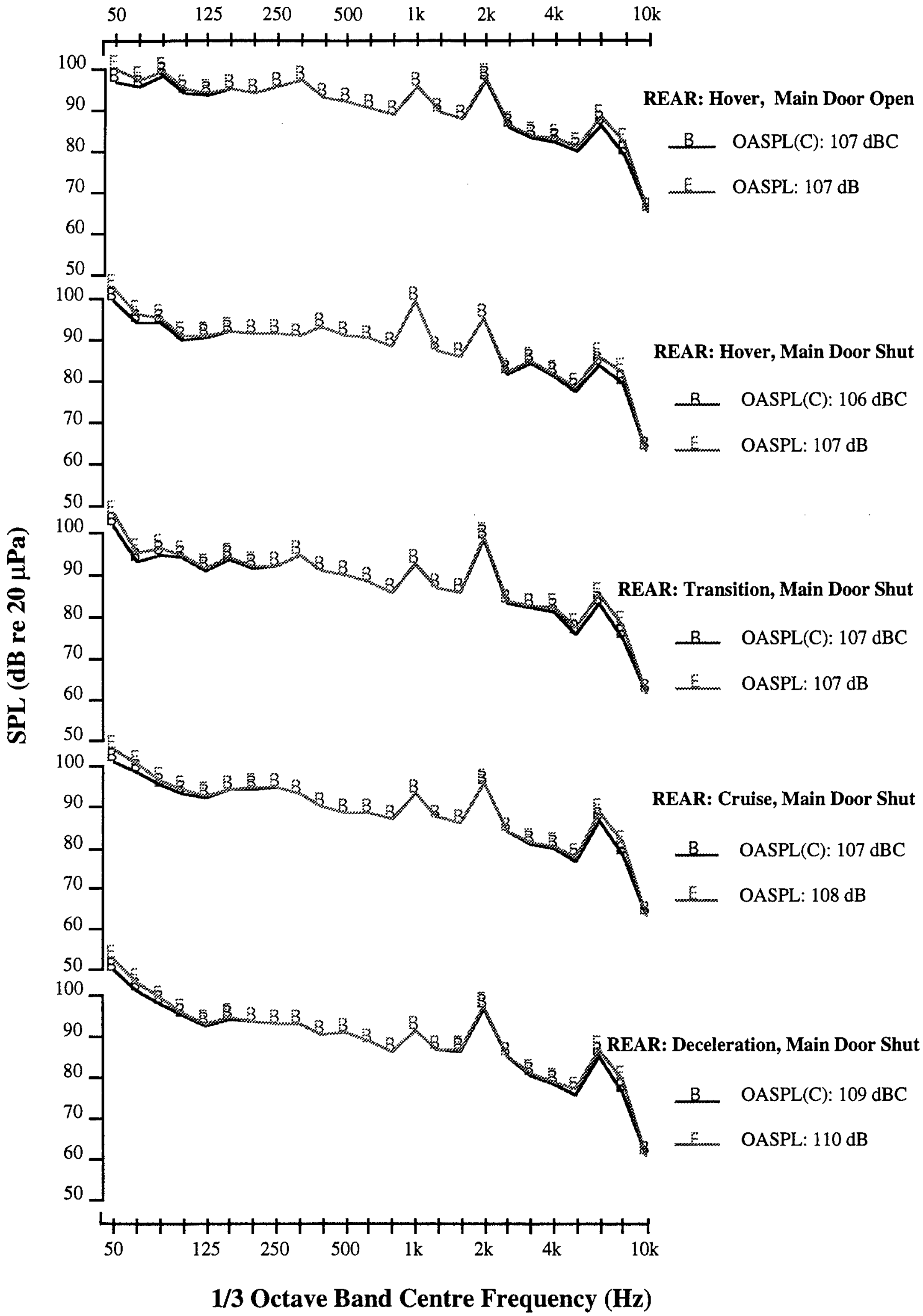


Figure 7. Third-octave analysis of the cabin noise measured at the Rear position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were open in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

Noise levels occurring in $^1/_3$ octave bands centred between 50 and 800 Hz are similar at the Pilot, Loadmaster and Middle positions. However, noise levels in bands centred between 1000 Hz and 10 kHz are significantly greater at the Loadmaster and Middle positions with high amplitude 'peaks' occurring in the bands centred at 1000 and 2000 Hz. It is possible that gearbox related noise is significantly higher at these locations in the cabin, with the peaks reflecting the main (planetary) meshing frequency of 980 Hz and the main bevel meshing frequency of 2012 Hz [ref 10].

In contrast, noise levels in $^1/_3$ octave bands centred between 1000 Hz and 10 kHz at the Rear position are slightly lower than those seen at the Loadmaster and Middle positions (although still higher than those seen at the Pilot position). This suggests that while the effect of gearbox related noise at the Rear position is greater than that seen at the Pilot position, it is not as pronounced as that seen at the Loadmaster and Middle positions. However, the Rear position is also unique in that significantly higher noise levels occur in bands centred between 50 and 100 Hz compared to those seen at the Pilot, Loadmaster and Middle positions. The Rear position may be particularly susceptible to aerodynamically generated noise created at the rotor blade pass frequency of 17 Hz with harmonically related repetitions occurring at 34, 51, 68 and 85 Hz [ref 10].

3.2 Ambient Levels and Acoustic Characteristics of External Noise During Ground Running

Table 2 shows the ambient external noise pressure levels (dBC re 20 μPa) measured at each position in each ground running condition. The highest SPL for each position is reported, whether measured in the head's left or right ear, in order to determine the 'worst case'. As Table 2 shows, while high ambient noise levels were measured at many positions in all ground running conditions, SPLs were excessive (>109 dBC):

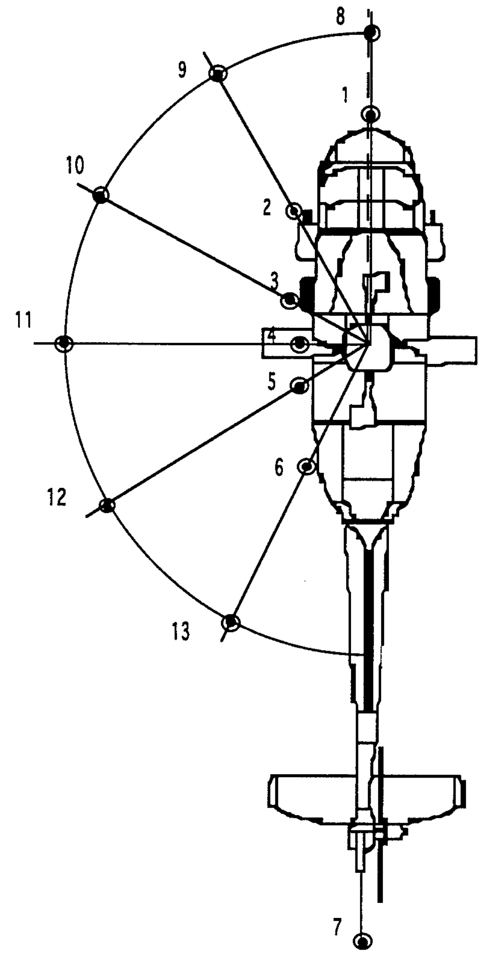
(a) at position 6 (close to the aircraft skin near the APU exhaust) when the APU (only) was running;

(b) at positions 1 through 6 (all positions close to the aircraft skin) when the APU and both turbines were running, although the level at position 6 (near to the APU exhaust) was significantly higher (>10 dB) than those measured at positions 1 through 5;

(c) at all positions when APU and both turbines were running with blades turning. In fact, levels were so high (>130 dB) at positions 6, 11, 12 and 13 in this condition that the recordings were distorted and it was not possible to determine the SPL accurately at these positions. In this condition, SPLs at the edge of the rotor tip path (positions 8 through 13) were higher than those seen at positions close to the aircraft skin (position 1 through 5) with exception of position 6 (close to the aircraft skin near the APU exhaust).

Table 2. Ambient external sound pressure levels (dBC re 20 μPa) measured at each position in each ground running condition.

Right: Measurement positions



Msmnt Posn	APU	APU and Turbines	APU and Turbines with Rotors Turning
1	76 dBC	109 dBC	118 dBC
2	84 dBC	106 dBC	114 dBC
3	90 dBC	109 dBC	114 dBC
4	96 dBC	111 dBC	115 dBC
5	98 dBC	114 dBC	117 dBC
6	118 dBC	124 dBC	>130 dBC
7	85 dBC	94 dBC	111 dBC
8	69 dBC	98 dBC	127 dBC
9	72 dBC	91 dBC	125 dBC
10	79 dBC	91 dBC	122 dBC
11	84 dBC	94 dBC	>130 dBC
12	86 dBC	97 dBC	>130 dBC
13	90 dBC	97 dBC	>130 dBC

Third-octave band analyses were performed in order to determine the acoustic characteristics of the external noise around the Black Hawk [ref 2]. Figures 8, 9 and 10 show analyses of the external noise 0.5 m and 8 m from the aircraft skin at the 90° azimuth position with the:

(a) APU running (Figure 8);

(b) APU running and both turbines at ground idle (Figure 9);

(c) APU running and both turbines at ground idle and rotors turning (Figure 10).

Analysis of the 90° azimuth position is reported because it is reasonably representative of the other azimuth positions. Analyses of the other azimuth positions are included in Appendix C.

As Figure 8 shows, the APU produces broadband noise with a noticeable peak occurring in $^1/_3$ octave bands centred at 6300 and 8000 Hz when close to the aircraft skin (0.5 m). Lower, but consistent noise levels (around 80 dB) occurred in bands centred between 250 and 500 Hz close to the aircraft when the APU was running, with slightly lower levels (around 70 dB) occurring in bands centred between 50 and 200 Hz. Increasing the distance from the aircraft to 8 m produced some noise reduction in all bands above 100 Hz, with a significant reduction in the levels in the bands centred at 6300 to 8000 Hz and those centred between 160 and 315 Hz. The high frequency attenuation is typical of high frequency 'fall-off' (with distance travelled by the acoustic wave), while the attenuation in the lower frequencies (160 to 315 Hz) seems to reflect a reduction in shaft related APU noise.

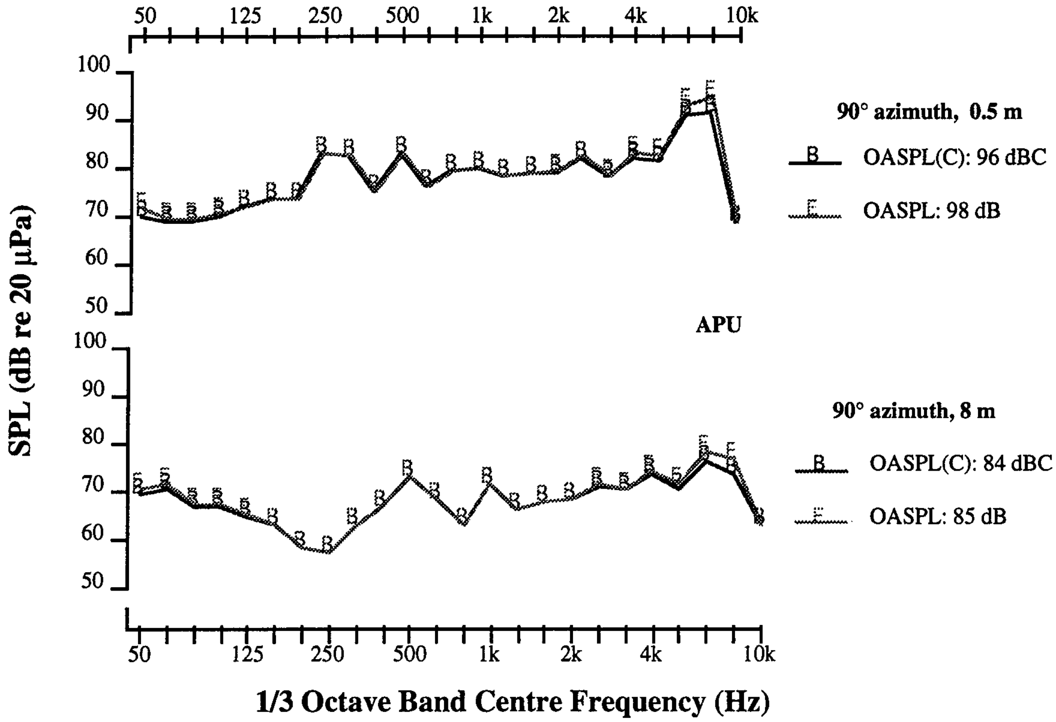


Figure 8. Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 90° azimuth position with the auxiliary power unit running.

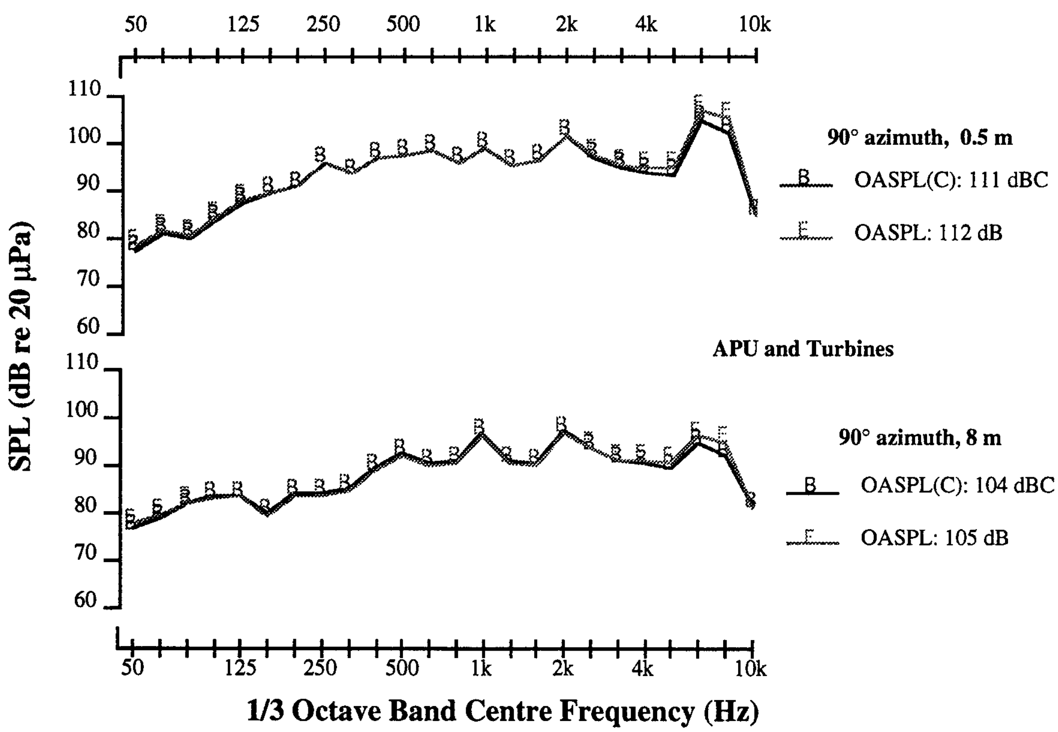


Figure 9. Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 90° azimuth position with the auxiliary power unit running and both turbines at ground idle.

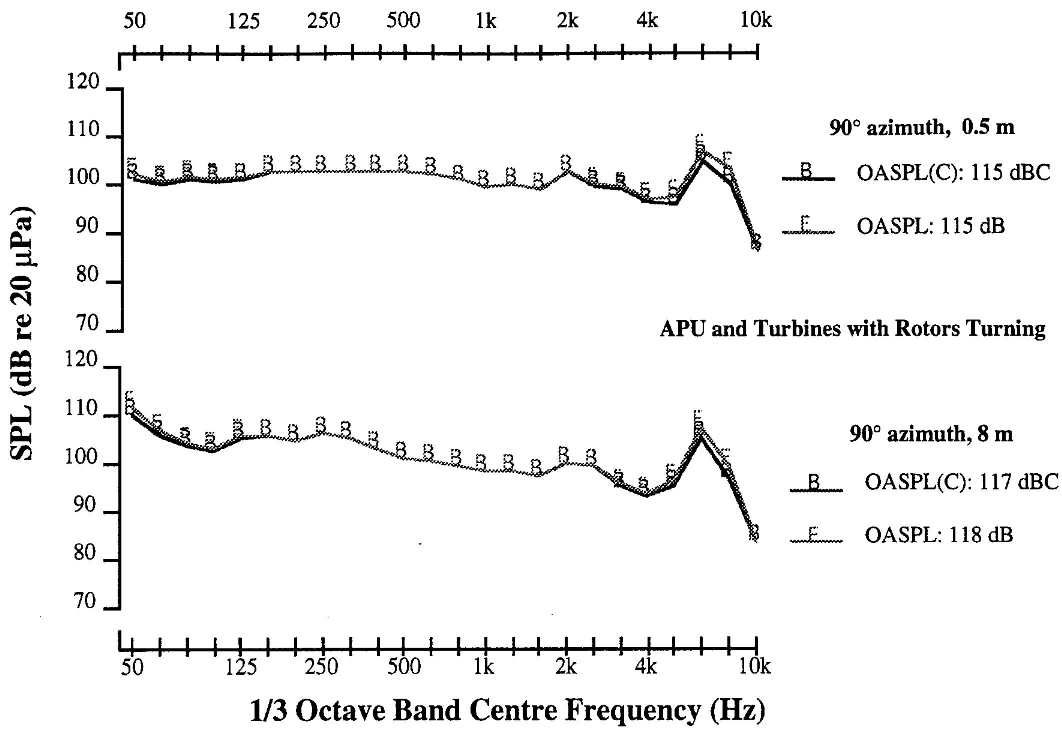


Figure 10. Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 90° azimuth position with the auxiliary power unit running, both turbines at ground idle and rotors turning.

Running both turbines at ground idle in addition to the APU served to increase the noise level in all $^1/_3$ octave bands by some 10 to 15 dB when close to the aircraft skin. The spectral shape does not change markedly from that seen with 'APU only', with the turbines 'reinforcing' the noise of the APU in a consistent fashion across all bands. Increasing the distance from the aircraft again produced some noise reduction in all bands above 1000 Hz (although not as great as that seen with the APU only running) with the greatest reduction again occurring in bands centred between 6300 to 8000 Hz and 160 to 315 Hz.

Figure 10 shows that the addition of the rotor components increases noise levels in bands centred between 50 and 125 Hz by 5 to 10 dB. This effect is more pronounced 8 m from the aircraft (just outside the rotor tip path), than close to the aircraft skin (0.5 m) and may be caused by noise generated aerodynamically at the rotor blade pass frequency of 17 Hz with harmonically related repetitions occurring at 34, 51, 68 and 85 Hz [ref 10].

3.3 Attenuation Characteristics of the ALPHA Helmet

Third-octave band analyses were also performed in order to determine frequencies attenuated by the ALPHA helmet (see Figure 11) [ref 2]. Helmet attenuation was defined as the difference between noise levels measured with (a) the 'bare' head, and (b) the head with the ALPHA helmet fitted in a constant flight condition (cruise flight). Measurements were repeated four times and the mean attenuation provided by the ALPHA helmet in each $^1/_3$ octave band calculated. The mean attenuation and the standard deviation associated with it are depicted in Figure 11.

The ALPHA helmet provides good attenuation (>15 dB) in $^1/_3$ octave bands centred between 315 Hz and 10 kHz (although attenuation performance does drop noticeably in the band centred

at 10 kHz) and some attenuation (5 to 10 dB) in bands centred between 200 and 250 Hz. Noise levels in bands centred between 50 and 160 Hz are amplified under the ALPHA helmet suggesting some resonance occurred in the HAM's ear canal simulator, or the helmet transferred some low frequency noise via vibration (analagous to bone conduction in the human head).

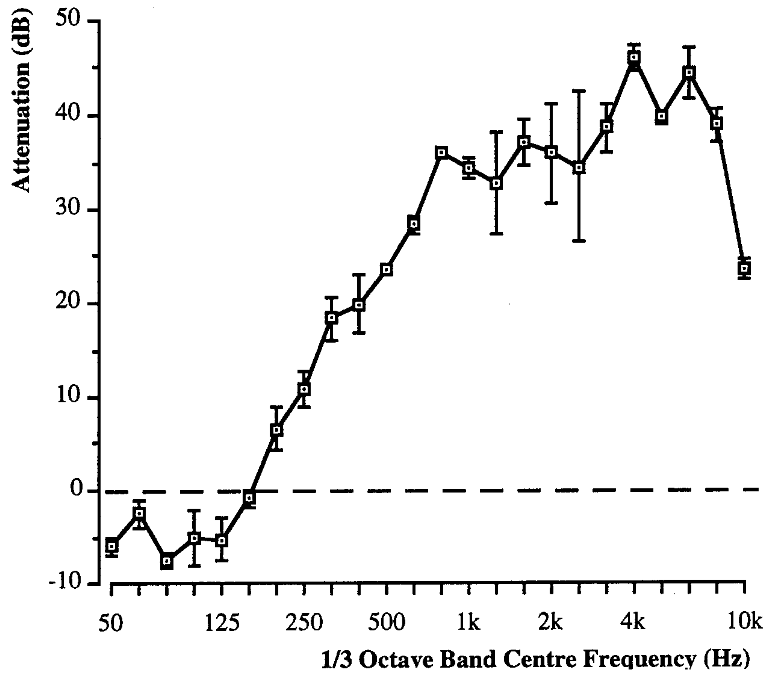


Figure 11. Mean attenuation provided by the ALPHA helmet in each 1/3 octave frequency band. The standard deviation associated with each mean is also shown.

3.4 Attenuation Characteristics of the EAR Earplug

Third-octave band analyses were also performed in order to determine frequencies attenuated by the EAR earplug [ref 2]. Earplug attenuation was defined as the difference between noise levels measured with (a) the 'bare' head, and (b) the head with an earplug inserted as deeply as possible in the ear canal in a constant flight condition (cruise flight). Measurements were repeated four times and the mean attenuation provided by the EAR earplug in each 1/3 octave band calculated. The mean attenuation and the standard deviation associated with it is shown in Figure 12.

The EAR ear plug provides good attenuation (>15 dB) in 1/3 octave bands centred between 315 Hz and 10 kHz (although attenuation performance does drop noticeably in the band centred at 10 kHz), and some attenuation (0 to 10 dB) in bands centred between 50 and 250 Hz.

3.5 Attenuation Characteristics of the Roanwell MX-2507 Communications Headset

Headset attenuation was defined as the difference between noise levels measured with (a) the 'bare' head, and (b) the head with a headset fitted in a constant flight condition (cruise flight). Measurements were repeated four times and the mean attenuation provided by the Roanwell headset in each 1/3 octave band calculated. The mean attenuation and the standard deviation associated with it are depicted in Figure 13. The Roanwell Headset provides good attenuation

(>15 dB) in 1/3 octave bands centred between 315 Hz and 10 kHz, and some attenuation (5 to 10 dB) in bands centred between 50 and 250 Hz.

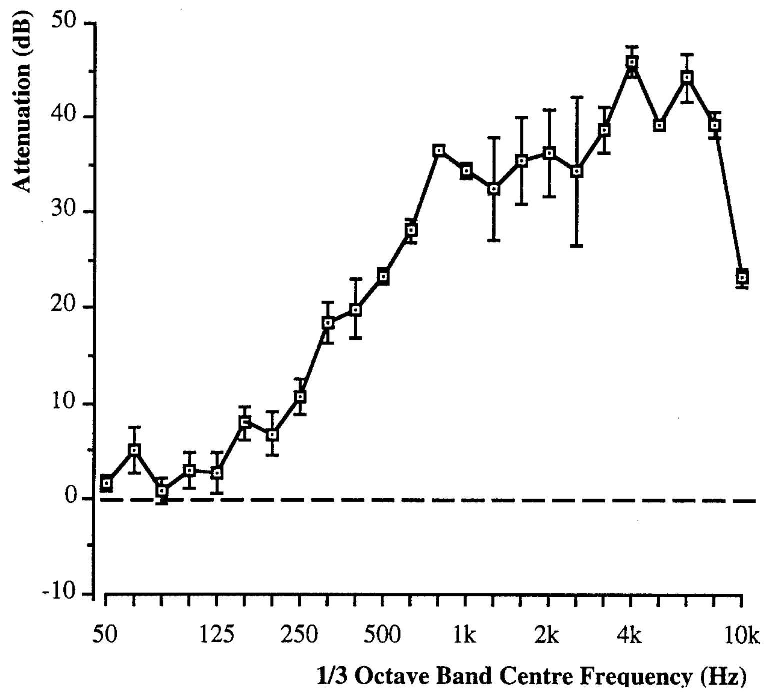


Figure 12. Mean attenuation provided by the EAR earplug in each 1/3 octave frequency band. The standard deviation associated with each mean is also shown.

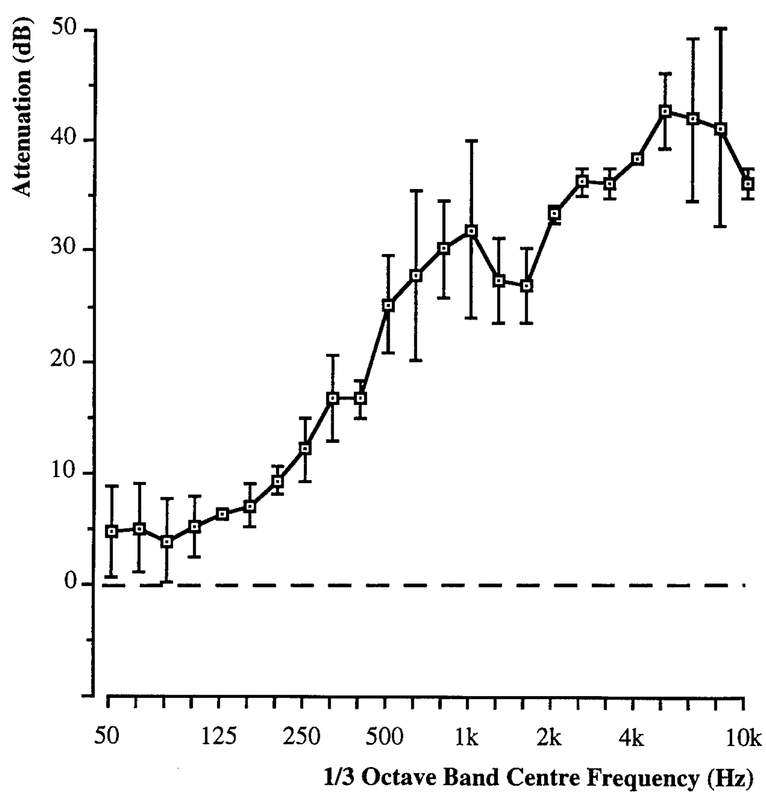


Figure 13. Mean attenuation provided by the Roanwell MX-2507 Communications Headset in each 1/3 octave frequency band. The standard deviation associated with each mean is also shown.

3.6 At-Ear SPLs During Flight

3.6.1 At-Ear SPLs at the Pilot and Loadmaster Positions When Wearing an ALPHA Helmet

Table 3 shows the at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing the the ALPHA helmet at the Pilot and Loadmaster positions in each flight condition (ie, the at-ear SPLs experienced by Pilots and Loadmasters wearing their normal HPDs at their normal positions in the aircraft). Also shown is the at-ear SPL experienced by the Loadmaster at the Winch position in the Hover, Main Door Open flight condition.

At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard deviation) provided by the ALPHA helmet from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

Table 3. At-ear sound pressure levels (dBA re 20 μPa) experienced by personnel wearing the ALPHA helmet at the Pilot and Loadmaster positions in each flight condition. Also shown is the at-ear SPL at the Winch position in the Hover, Main Door Open flight condition.

	Main Door Open		Main Door Shut	
	LM Wndw Open	**LM Wndw Shut**	**LM Wndw Open**	**LM Wndw Shut**
Hover	**Pilot:** 87 dBA **LM:** 91 dBA **Winch:** 87 dBA	**Pilot:** 87 dBA **LM:** 87 dBA **Winch:** 88 dBA	**Pilot:** 88 dBA **LM:** 89 dBA	**Pilot:** 89 dBA **LM:** 87 dBA
Transition	—	—	**Pilot:** 88 dBA **LM:** 90 dBA	**Pilot:** 88 dBA **LM:** 86 dBA
Cruise	—	—	**Pilot:** 89 dBA **LM:** 89 dBA	**Pilot:** 90 dBA **LM:** 87 dBA
Deceleration	—	—	**Pilot:** 90 dBA **LM:** 92 dBA	**Pilot:** 86 dBA **LM:** 89 dBA

3.6.2 At-Ear SPLs at the Middle and Rear Positions When Wearing EAR Earplugs

Table 4 shows the at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing EAR earplugs at the Middle and Rear positions in each flight condition (ie, the at-ear SPLs experienced by troops wearing their normal HPDs at their normal positions in the aircraft).

At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard deviation) provided by the EAR earplug from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

Table 4. At-ear sound pressure levels (dBA re 20 μPa) experienced by personnel wearing EAR earplugs at the Middle and Rear positions in each flight condition.

	Main Door Open		Main Door Shut	
	LM Wndw Open	LM Wndw Shut	LM Wndw Open	LM Wndw Shut
Hover	Mid: 88 dBA Rear: 86 dBA	Mid: 88 dBA Rear: 86 dBA	Mid: 85 dBA Rear: 83 dBA	Mid: 84 dBA Rear: 83 dBA
Transition	—	—	Mid: 84 dBA Rear: 83 dBA	Mid: 81 dBA Rear: 82 dBA
Cruise	—	—	Mid: 83 dBA Rear: 84 dBA	Mid: 82 dBA Rear: 82 dBA
Deceleration	—	—	Mid: 84 dBA Rear: 85 dBA	Mid: 83 dBA Rear: 85 dBA

3.6.3 At-Ear SPLs at the Middle and Rear Positions When Wearing the Roanwell MX-2507 Communications Headset

Table 5 shows the at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing the Roanwell MX-2507 Communications Headset at the Middle and Rear positions in each flight condition (ie, the at-ear SPLs experienced by maintenance crew wearing their normal HPDs at their normal positions in the aircraft).

At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard deviation) provided by the Roanwell Headset from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

Table 5. At-ear sound pressure levels (dBA re 20 μPa) experienced by personnel wearing the Roanwell MX-2507 Communications Headset at the Middle and Rear positions in each flight condition.

	Main Door Open		Main Door Shut	
	LM Wndw Open	LM Wndw Shut	LM Wndw Open	LM Wndw Shut
Hover	Mid: 88 dBA Rear: 86 dBA	Mid: 89 dBA Rear: 86 dBA	Mid: 86 dBA Rear: 84 dBA	Mid: 85 dBA Rear: 84 dBA
Transition	—	—	Mid: 85 dBA Rear: 84 dBA	Mid: 82 dBA Rear: 83 dBA
Cruise	—	—	Mid: 85 dBA Rear: 84 dBA	Mid: 83 dBA Rear: 82 dBA
Deceleration	—	—	Mid: 84 dBA Rear: 85 dBA	Mid: 83 dBA Rear: 85 dBA

3.7 At-Ear SPLs During Ground Running

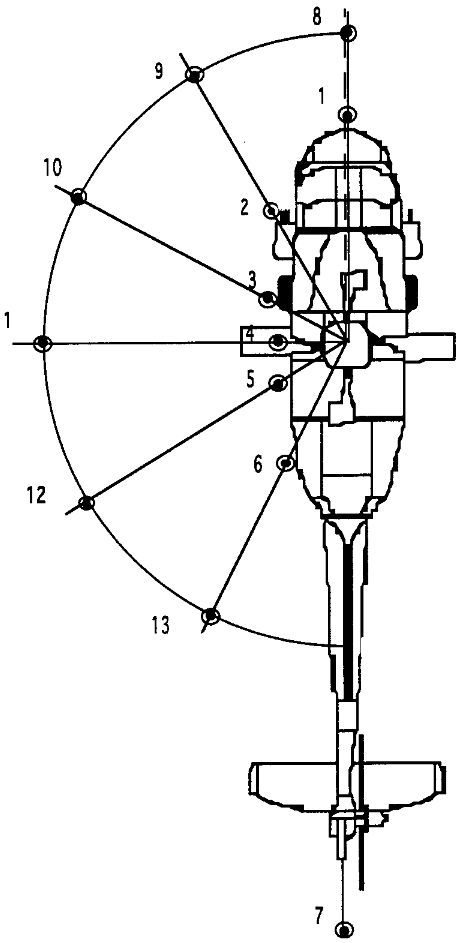
3.7.1 At-Ear SPLs When Wearing an ALPHA Helmet

The at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing the ALPHA helmet at each external measurement position in each ground running condition are shown in Table 6. At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard deviation) provided by the ALPHA from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

Table 6. At-ear sound pressure levels (dBA re 20 μPa) experienced by personnel wearing the ALPHA helmet at each position in each ground running condition.

Right: Measurement positions

Msmnt Posn	APU	APU and Turbines	APU and Turbines with Rotors Turning
1	60 dBA	85 dBA	102 dBA
2	68 dBA	80 dBA	98 dBA
3	69 dBA	83 dBA	98 dBA
4	71 dBA	86 dBA	98 dBA
5	74 dBA	90 dBA	99 dBA
6	92 dBA	99 dBA	>114 dBA
7	67 dBA	75 dBA	95 dBA
8	52 dBA	73 dBA	114 dBA
9	58 dBA	65 dBA	111 dBA
10	61 dBA	68 dBA	108 dBA
11	62 dBA	71 dBA	>114 dBA
12	62 dBA	73 dBA	>114 dBA
13	70 dBA	83 dBA	>114 dBA



It was not possible to calculate at-ear SPLs at positions 11, 12 and 13 when the APU and both turbines were running with blades turning because levels were so high at these positions that the 'bare' head recordings were distorted and ambient SPLs could not be determined (see Section 3.2). However, at-ear levels when wearing the ALPHA helmet at these positions were certainly higher than those seen at position 8 (114 dBA), which produced the highest level without distorting the recordings.

3.7.2 At-Ear SPLs When Wearing EAR Earplugs

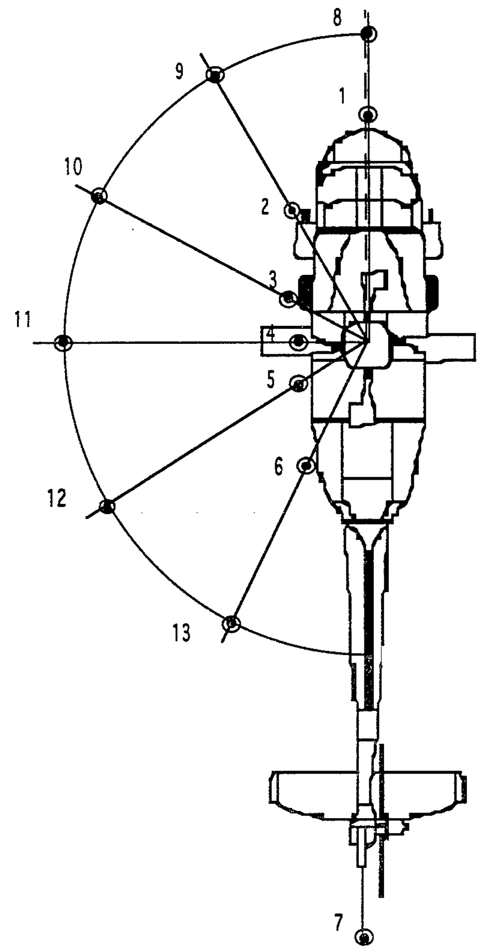
Table 7 shows the at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing EAR earplugs at each external measurement position in each ground running condition. At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard

deviation) provided by the EAR earplug from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

Table 7. At-ear sound pressure levels (dBA re 20 μPa) experienced by personnel wearing EAR earplugs at each position in each ground running condition.

Right: Measurement positions

Msmnt Posn	APU	APU and Turbines	APU and Turbines with Rotors Turning
1	55 dBA	82 dBA	96 dBA
2	62 dBA	78 dBA	92 dBA
3	65 dBA	82 dBA	92 dBA
4	67 dBA	83 dBA	93 dBA
5	70 dBA	86 dBA	93 dBA
6	87 dBA	95 dBA	>106 dBA
7	60 dBA	71 dBA	89 dBA
8	46 dBA	71 dBA	106 dBA
9	51 dBA	63 dBA	103 dBA
10	54 dBA	64 dBA	101 dBA
11	57 dBA	67 dBA	>106 dBA
12	58 dBA	70 dBA	>106 dBA
13	65 dBA	80 dBA	>106 dBA



At-ear SPLs at positions 11, 12 and 13 when the APU and both turbines were running with blades turning could not be calculated because of the reasons outlined above (see Sections 3.7.1 and 3.2). However, at-ear levels when wearing EAR earplugs at these positions were certainly higher than those seen at position 8 (106 dBA), where the highest undistorted levels were recorded.

3.7.3 At-Ear SPLs When Wearing the Roanwell MX-2507 Communications Headset

The at-ear SPLs (dBA re 20 μPa) experienced by personnel wearing the Roanwell MX-2507 Communications Headset at each external measurement position in each ground running condition are shown in Table 8. At-ear SPLs were calculated by subtracting the corrected attenuation (mean attenuation minus one standard deviation) provided by the Roanwell Headset from the SPL measured with the 'bare' head in each measurement position (see Section 2.5).

At-ear SPLs at positions 11, 12 and 13 when the APU and both turbines were running with blades turning could not be calculated (see Sections 3.7.1 and 3.2). However, at-ear levels when wearing the Roanwell Headset at these positions were certainly higher than those measured at position 8 (106 dBA), which produced the highest levels without distorting the recordings.

13. We would now like you to rate the speech your hear over the radio for (i) Intelligibility, (ii) Clarity and (iii) The Attention Demand required for understanding the speech.

(a) Rate the speech you hear through your own 'stock' helmet:

	1	2	3	4	5	6	7	
LOW INTELLIGIBILITY	1	2	3	4	5	6	7	HIGH INTELLIGIBILITY
LOW CLARITY	1	2	3	4	5	6	7	HIGH CLARITY
HIGH ATTENTION NEEDED	1	2	3	4	5	6	7	LOW ATTENTION NEEDED

(b) Rate the speech you heard through the ANR helmet with ANR ON:

	1	2	3	4	5	6	7	
LOW INTELLIGIBILITY	1	2	3	4	5	6	7	HIGH INTELLIGIBILITY
LOW CLARITY	1	2	3	4	5	6	7	HIGH CLARITY
HIGH ATTENTION NEEDED	1	2	3	4	5	6	7	LOW ATTENTION NEEDED

(c) Rate the speech you heard through the ANR helmet with ANR OFF:

	1	2	3	4	5	6	7	
LOW INTELLIGIBILITY	1	2	3	4	5	6	7	HIGH INTELLIGIBILITY
LOW CLARITY	1	2	3	4	5	6	7	HIGH CLARITY
HIGH ATTENTION NEEDED	1	2	3	4	5	6	7	LOW ATTENTION NEEDED

The auditory environment in the Black Hawk results from a complex acoustic interaction with aerodynamic noise produced predominantly at lower frequencies (below 100 Hz) and similar levels at the Pilot, Loadmaster and Middle positions in the aircraft, and at significantly higher levels at the Rear position. Mechanical noise is produced predominantly at higher frequencies (above 980 Hz) and at higher levels at the Loadmaster and Middle positions.

The ALPHA helmet does serve to reduce the cabin noise level considerably before it reaches the ear (see Sections 3.1 and 3.6.1). However, current hearing conservation regulations recommend a PNE of 85 dBA for an 8 hr day [ref 1], and aircrew sitting at the Pilot and Loadmaster positions would exceed this limit if flying in excess of 2 to 3 hr per day. In cruise flight with Loadmaster windows shut, for example, a Pilot wearing an ALPHA helmet is receiving 90 dBA at-ear and could only could only fly for 2 hr 31 min before exceeding his PDED limit. Aircrew (Pilots and Loadmasters) in the S-70A-9 need to

(a) have their exposure times limited to around 2 to 3 hr, or

(b) be provided with additional hearing protection

in order to meet the recommended Permissible Daily Exposure Dose (PDED) of 85 dBA for an 8 hr day. Clearly, (b) is the preferred solution and aircrew will have to be supplied with additional hearing protection in order to maintain reasonable manning levels for operational flying.

Recommendation 1. It is recommended that Pilots and Loadmasters flying in the Black Hawk be provided with additional hearing protection in order to meet hearing conservation regulations and maintain reasonable manning levels for operational flying.

There are currently two types of device available which can be used in conjunction with standard aircrew helmets currently used to provide additional hearing protection. These consist of:

(a) soft insert earplugs, such as the EAR earplug, that are inserted in the ear canal and worn under the standard helmet;

(b) Active Noise Reduction (ANR) Systems, such as that developed by the UK Defence Research Agency (DRA), that can be fitted in standard earshells and mounted in the ALPHA helmet [ref 8].

The use of earplugs in conjunction with the ALPHA helmet would be expedient and provide a solution to the problem outlined above. The combination of these devices will provide an additional attenuation of 5 dBA at-ear[4] (at least) allowing Pilots and Loadmasters to fly for at least 8 hr without exceeding the recommended PNE.

However, the use of dual protection may not be the most effective solution for the Black Hawk environment. The ALPHA helmet and the EAR earplug have similar attenuation profiles —

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[4]It has long been recognised that while combining HPDs in this way provides additional hearing protection, the resultant noise reduction falls well short of the algebraic sum of the attenuation of the individual devices. An increase in overall attenuation of 5 dBA is generally regarded as an acceptable and conservative estimate [refs 5, 6 and 7].

each adequately attenuates high frequency noise, but provides limited attenuation at frequencies below 250 Hz and virtually no attenuation at frequencies below 160 Hz (indeed the ALPHA helmet amplifies noise at frequencies below 160 Hz, see Sections 3.3 and 3.4). Earplugs fail to attenuate the high noise levels that are generated at frequencies below 250 Hz in the Black Hawk (see Section 3.1.1). Anecdotal evidence also suggests that earplugs hinder Inter-Communication System (ICS) and radio communications. Aircrew report having to increase the communications volume to such a level that transmissions are heavily distorted as well as being 'masked' by the earplug. Questions have also been raised in relation to discomfort and the operational problems associated with wearing a device that may well 'pop out' in flight if incorrectly fitted and that can also cause health problems in humid conditions.

Recommendation 2. It is recommended that Pilots and Loadmasters flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the ALPHA helmet in order to meet current hearing conservation regulations and maintain reasonable manning levels for operational flying. However, earplugs may not be the most effective acoustic solution for the Black Hawk noise environment.

Unlike the passive noise attenuation provided by helmets and earplugs, ANR actually cancels some of the noise by generating an acoustic waveform that is (ideally) 180° out of phase with the noise inside the earcup and adding this "anti-noise" to the earcup. The Aerospace Division of DRA has been developing an ANR system mounted within the earcups of a standard ALPHA helmet for a number of years. In the DRA ANR system, noise in the earcup is sampled via a microphone, phase inverted and then reintroduced into the earcup. A separate circuit pre-emphasises ICS and re-introduces it directly into the earcup to ensure ICS integrity and that the system 'fails safe' (ie, ICS capability remains even if the ANR system fails). Assessment of DRA's prototype ANR system [ref 8] showed it effectively reduced at-ear SPLs and offered a number of advantages over earplugs in the helicopter environment because it:

(a) effectively cancelled low frequency noise under 250 Hz;

(b) enhanced ICS communication.

DRA's Mk II model ANR system is purportedly superior to the prototype in both these respects. Such a system may well prove to be the most effective acoustic solution in the Black Hawk noise environment, although they would be more expensive to purchase and require more logistic support than the earplug solution.

Recommendation 3. It is recommended that helmet mountable ANR systems (such as that produced by the UK Defence Research Agency) be assessed for their effectiveness in the Black Hawk acoustic environment.

The Roanwell MX-2507 Communications Headset provides enough hearing protection to allow maintenance crew sitting in the rear section of the aircraft a PDED of 8 hr (see Tables 6 and 7). The only flight condition which consistently produces an at-ear SPL exceeding 85 dBA is hovering with the main door open. Maintenance crew wearing the Roanwell Headset would exceed their PDED after some 3 hr 10 min in this flight condition. However, it is unlikely maintenance crew would be present in missions involving some period of time in the hover with the main door open (eg, search and rescue or underslung cargo work).

While there is no requirement for maintenance crew wearing the Roanwell Communications Headset to wear additional hearing protection devices in order to meet hearing conservation regulations, practical problems relating to the communications system in the aircraft will arise if they do not do so. The Black Hawk has no individual volume control available at the various ICS connection points in the rear of the aircraft — the volume at every point in the aircraft is set via a master volume control at the Pilot position. If Pilots (and Loadmasters) are wearing earplugs under their helmets, the SPL of the communications will be set to compensate for the presence of the earplugs and thus be extremely high for any person not wearing earplugs. For these reasons, it is sensible to recommend that maintenance crew members also wear earplugs (such as the EAR) under their communications headsets.

Recommendation 4. It is recommended that maintenance crew flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the Roanwell MX-2507 Communications Headset in order to reduce exposure to communications traffic with a high SPL.

The EAR earplug provides enough hearing protection to allow troops sitting in the rear section of the aircraft a PDED of 8 hr (see Tables 6 and 7). Once again, the only flight condition which consistently produces an at-ear SPL exceeding 85 dBA is hovering with the main door open, and it is unlikely that troops would be present in missions involving extended exposure in this particular flight condition. However, it should be noted that this finding is linked directly to the attenuation properties of the EAR earplug, and that troops must be issued with the EAR earplug or an earplug with equivalent attenuation properties. One method of specifying equivalency is to use the Sound Level Conversion (SLC_{80}) rating. The SLC_{80} is a rating which reflects the general attenuation performance of the earplug and guarantees the earplug will provide this level of performance for 80% of wearers. The EAR earplug has an SLC_{80} rating of 22 [ref 9] and any earplug used should have an equivalent or higher SLC_{80} rating. The earplug must also be fitted properly, and brief instruction to this effect should be included in the standard pre-flight safety briefing.

Recommendation 5. It is recommended that troops flying in the Black Hawk be required to wear earplugs with a SLC_{80} rating of 22 or higher (such as the EAR earplug). The earplugs must be fitted properly and adequate instruction to this effect should be included in the standard pre-flight safety briefing.

4.2 Ambient External Noise Levels During Ground Running

High ambient noise levels were also measured at many positions in all ground running conditions, with particularly high levels apparent (see Table 2):

(a) close to the aircraft skin near the APU exhaust when the APU (only) was running;

(b) at all positions close to the aircraft skin when the APU and both turbines were running, although the level near the APU exhaust was significantly higher (>10 dB) that those measured at the other positions close to the aircraft skin;

(c) at all positions when the APU and both turbines were running with blades turning. In this condition, SPLs at the edge of the rotor tip path were noticeably higher than those seen close to the aircraft skin (with the one exception of the position near the APU exhaust).

Noise generated by the APU was essentially broadband in nature with the high frequency (>1 kHz) component of the noise tending to 'fall-off' with distance (see Section 3.2.1). Noise generated by the turbines was also essentially broadband in nature and tended to 'reinforce' the noise of the APU by generally increasing its level at all frequencies rather than substantially altering its spectral shape. Noise generated by the rotors significantly increased the levels of low frequency noise (>125 Hz), with these effects being more pronounced at the edge of the rotor tip path than close to the aircraft skin. This increase in low frequency SPL can be attributed to noise generated aerodynamically at the rotor blade pass frequency (17 Hz with harmonically related repetitions at 34, 51, 68 and 85 Hz).

The ALPHA helmet, the Roanwell Headset and the EAR earplug provide enough hearing protection to allow current hearing conservation regulations to be met at most positions external to the aircraft when the APU (only) and APU and turbines are running. However, positions close to the aircraft skin near the APU exhaust do produce at-ear SPLs exceeding 85 dBA in these two ground running conditions (see Tables 6, 7 and 8). As a worst case, maintenance crew members wearing Roanwell Headsets and working in this area would receive 97 dBA at ear and exceed their PDED after 30 min exposure with APU and turbines running (see Table 7).

Given that maintenance crew do often work close to this area (doing compressor washes, for example) it would be prudent to recommend that they wear earplugs and their communication headsets (or a muff-type HPD with attenuation properties equivalent to the Roanwell Headset) any time they are working around the aircraft with APU and/or turbines running. Even 'dual hearing protection' will not bring at-ear SPLs at these positions down to 85 dBA (at-ear SPL would be 92 dBA in the case described above, with a maximum exposure time of 1 hr 35 min) when the APU and turbines are running. Maintenance crews should not work for longer than 1 hr 35 min at positions near the APU exhaust when the APU and turbines are running, even when wearing headsets and earplugs.

Recommendation 6. *It is recommended that maintenance crew wear earplugs (such as the EAR earplug) in combination with the Roanwell Headset (or an equivalent muff type HPD) any time they are working around the Black Hawk with APU and/or turbines running with rotors stopped. Maintainers should not work for longer than 1.5 hr per day at positions near the APU exhaust when the APU and turbines are running with rotors stopped, even when wearing earplugs in combination with the headset.*

It would also be prudent to recommend that aircrew wear earplugs and their ALPHA helmets any time they are walking around a Black Hawk that has its APU and/or turbines running. A Pilot or Loadmaster wearing an ALPHA helmet would receive 99 dBA at ear and exceed the recommended PDED after 19 min exposure if standing near the APU exhaust with APU and turbines running (see Table 6). Once more 'dual hearing protection' will not bring at-ear SPLs at these positions down to 85 dBA (at-ear SPL would be 94 dBA in the case described above, with a maximum exposure time of 1 hr) when the APU and turbines are running. Aircrew should not occupy positions near the APU exhaust when the APU and turbines are running for longer than 1 hr, even when wearing helmets and earplugs.

Recommendation 7. It is recommended that aircrew wear earplugs (such as the EAR earplug) in combination with their ALPHA helmet any time they are walking around the Black Hawk with APU and/or turbines running with rotors stopped. When the APU and turbines are running with rotors stopped, aircrew should not occupy positions near the APU exhaust for longer than 1 hr per day even when wearing earplugs in combination with the ALPHA helmet.

The ground running condition of APU and turbines running with blades turning poses a serious problem in terms of the at-ear SPLs experienced by maintenance crew and aircrew. Even when wearing the ALPHA helmet and earplugs, aircrew are receiving at least 109 dBA at-ear[5] at (a) positions close to the aircraft skin near the APU exhaust and (b) a number of positions at the edge of the rotor sweep (see Tables 7 and 8). Total allowable exposure time in these instances is in the order of 2 min, and brief exposures will still significantly reduce PDEDs. Maintainers wearing the Roanwell Headset (or an equivalent earmuff) and an earplug are receiving at least 101 dBA at-ear at these positions, with an associated maximum daily exposure time of 12 min. Positions close to the aircraft skin forward of the cabin door produce the lowest at-ear SPLs with aircrew wearing ALPHA helmets and earplugs receiving around 97 dBA at-ear (maximum exposure time 30 min) and maintainers wearing Roanwell Headsets (or an equivalent earmuff) and earplugs receiving around 91 dBA at-ear (maximum exposure time 2 hr).

These results indicate that even when wearing double hearing protection, maintenance crew and aircrew should not occupy positions close to the APU exhaust or at the edge of the rotor sweep when the APU and turbines are running with rotors turning. In particular, the practice of holding passengers and support crew at the edge of the rotor sweep prior to approaching the aircraft should be abandoned, or at least modified so that passengers and support crew stand well back from the edge of the rotor sweep. This would reduce the noise hazard to passengers and support crew and still allow the pilot to see them and signal that they can proceed when safe to do so.[6] If there is a requirement for maintenance crew or aircrew to occupy a position external to the aircraft when APU and turbines are running with rotors turning the quietest positions are forward of the main cabin door close to the aircraft skin. Maintenance and aircrew should be aware that even at these positions their maximum exposure time is limited to around 2 hr and 30 min per day respectively. If there is any requirement to occupy a position near the APU exhaust while the APU and turbines are running with rotors turning, the maximum exposure time for maintenance crew and aircrew is in the order of 12 and 2 min per day respectively.

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[5]Once again it should be pointed out that it was not possible to calculate at-ear SPLs at these positions when the APU and both turbines were running with blades turning because levels were so high at these positions the 'bare' head recordings were distorted and ambient SPLs could not be determined (see Section 3.2).

[6]Empirical measurement will be required to determine the distance from the edge of the rotor sweep at which the noise hazard is reduced. Consideration will also have to be given as to whether the pilot can perform his 'safety responsibilities' to passengers and support crew standing at this distance.

Recommendation 8. It is recommended that maintenance crew and aircrew should not occupy positions close to the APU exhaust or at the edge of the rotor sweep when the APU and turbines are running with rotors turning, even when wearing earplugs (such as the EAR earplug) in combination with the ALPHA helmet or Roanwell Headset (or equivalent muff). The practice of holding passengers and support crew at the edge of the rotor sweep prior to approaching the aircraft should be abandoned, or at least modified so that passengers and support crew stand well back from the edge of the rotor sweep. If there is a requirement for maintenance crew or aircrew to occupy a position external to the aircraft when APU and turbines are running with rotors turning, the quietest positions are forward of the main cabin door close to the aircraft skin. Maintenance crew and aircrew should be aware that even at these positions their maximum exposure time is limited to around 2 hr and 30 min per day respectively. If there is any requirement to occupy a position near the APU exhaust or at the edge of the rotor sweep while the APU and turbines are running with rotors turning, the maximum exposure time for maintenance crew and aircrew is in the order of 12 and 2 min per day respectively.

5. CONCLUSION

This document reports the results of a comprehensive noise survey of the Sikorsky S-70A-9 Black Hawk helicopter environment and an assessment of the hearing protection devices worn by personnel exposed to this environment. These results are discussed in relation to current hearing conservation regulations which allow a permissible noise exposure of 85 dBA for an 8 hr working day [ref 1].

Recommendations are:

1. That Pilots and Loadmasters flying in the Black Hawk be provided with additional hearing protection devices and instructed in their use in order to meet current hearing conservation regulations and maintain reasonable manning levels for operational flying.

2. That Pilots and Loadmasters flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the ALPHA helmet in order to meet current hearing conservation regulations and maintain reasonable manning levels for operational flying. However, earplugs may not be the most effective acoustic solution for the Black Hawk noise environment.

3. That helmet mountable ANR systems (such as that produced by the UK Defence Research Agency) be assessed for their effectiveness in the Black Hawk acoustic environment.

4. It is recommended that maintenance crew flying in the Black Hawk use earplugs (such as the EAR earplug) in combination with the Roanwell MX-2507 Communications Headset in order to reduce exposure to communications traffic with a high sound pressure levels.

5. That troops flying in the Black Hawk be required to wear earplugs with a SLC_{80} rating of 22 or higher (such as the EAR earplug). The earplugs must be fitted properly and adequate instruction to this effect should be included in the standard pre-flight safety briefing.

6. That maintenance crew wear earplugs (such as the EAR earplug) in combination with the Roanwell Headset (or an equivalent muff type hearing protection device) any time they

are working around the Black Hawk with APU and/or turbines running with rotors stopped. Maintainers should not work for longer than 1.5 hr per day at positions near the APU exhaust when the APU and turbines are running with rotors stopped, even when wearing earplugs in combination with the headset.

7. That aircrew wear earplugs (such as the EAR earplug) in combination with their ALPHA helmet any time they are walking around the Black Hawk with APU and/or turbines running with engines stopped. When the APU and turbines are running with rotors stopped, aircrew should not occupy positions near the APU exhaust for longer than 1 hr per day even when wearing earplugs in combination with the ALPHA helmet.

8. That maintenance crew and aircrew should not occupy positions close to the APU exhaust or at the edge of the rotor sweep when the APU and turbines are running with rotors turning, even when wearing earplugs (such as the EAR earplug) in combination with the ALPHA helmet or Roanwell Headset (or equivalent muff). The practice of holding passengers and support crew at the edge of the rotor sweep prior to approaching the aircraft should be abandoned, or at least modified so that passengers and support crew stand well back from the edge of the rotor sweep. If there is a requirement for maintenance crew or aircrew to occupy a position external to the aircraft when APU and turbines are running with rotors turning, the quietest positions are forward of the main cabin door close to the aircraft skin. Maintenance crew and aircrew should be aware that even at these positions their maximum exposure time is limited to around 2 hr and 30 min per day respectively. If there is any requirement to occupy a position near the APU exhaust or at the edge of the rotor sweep while the APU and turbines are running with rotors turning, maintenance crew and aircrew should be aware that the maximum exposure time is in the order of 12 and 2 min per day respectively.

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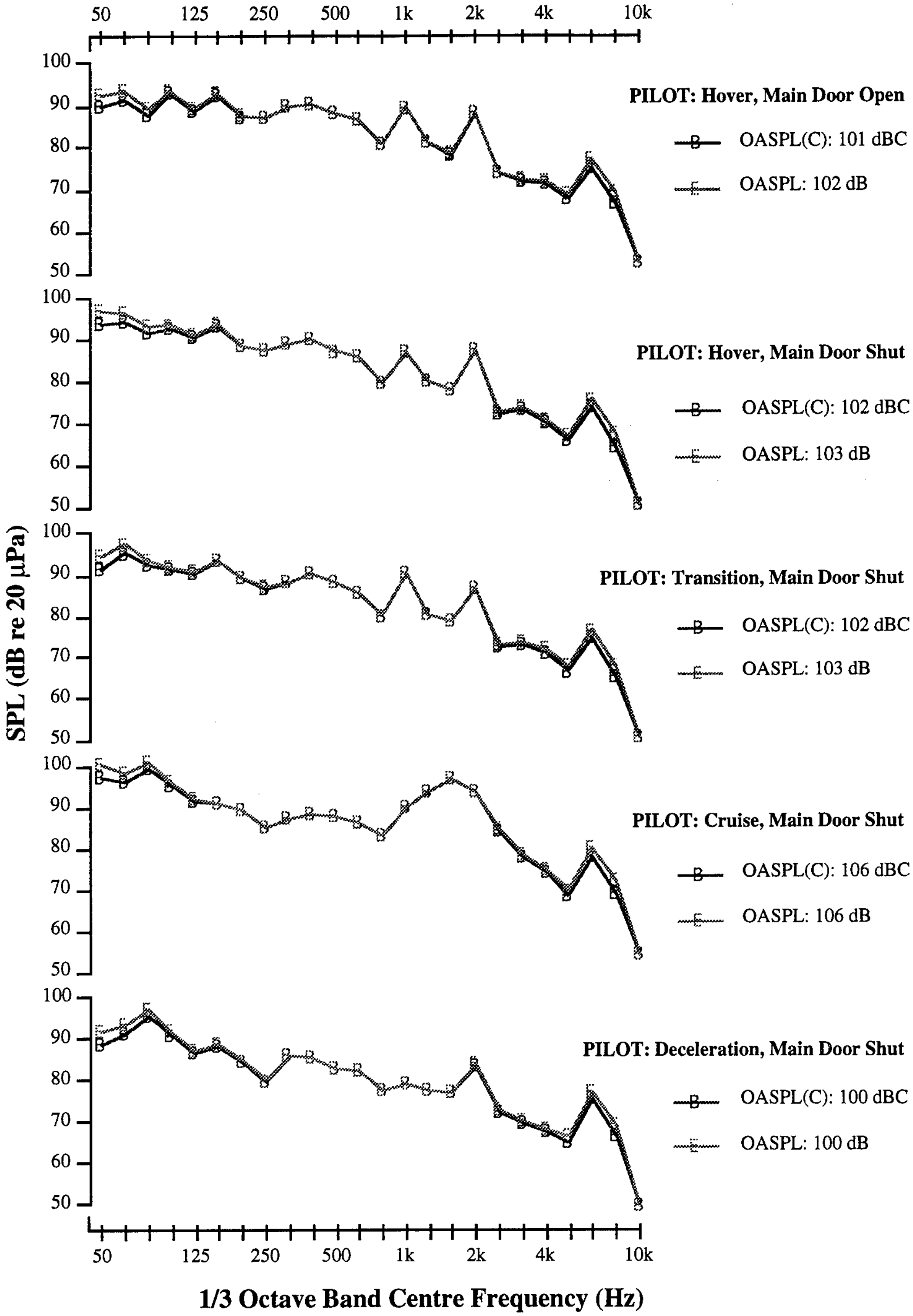
APPENDIX A

A and C frequency weighting curves for third-octave bands

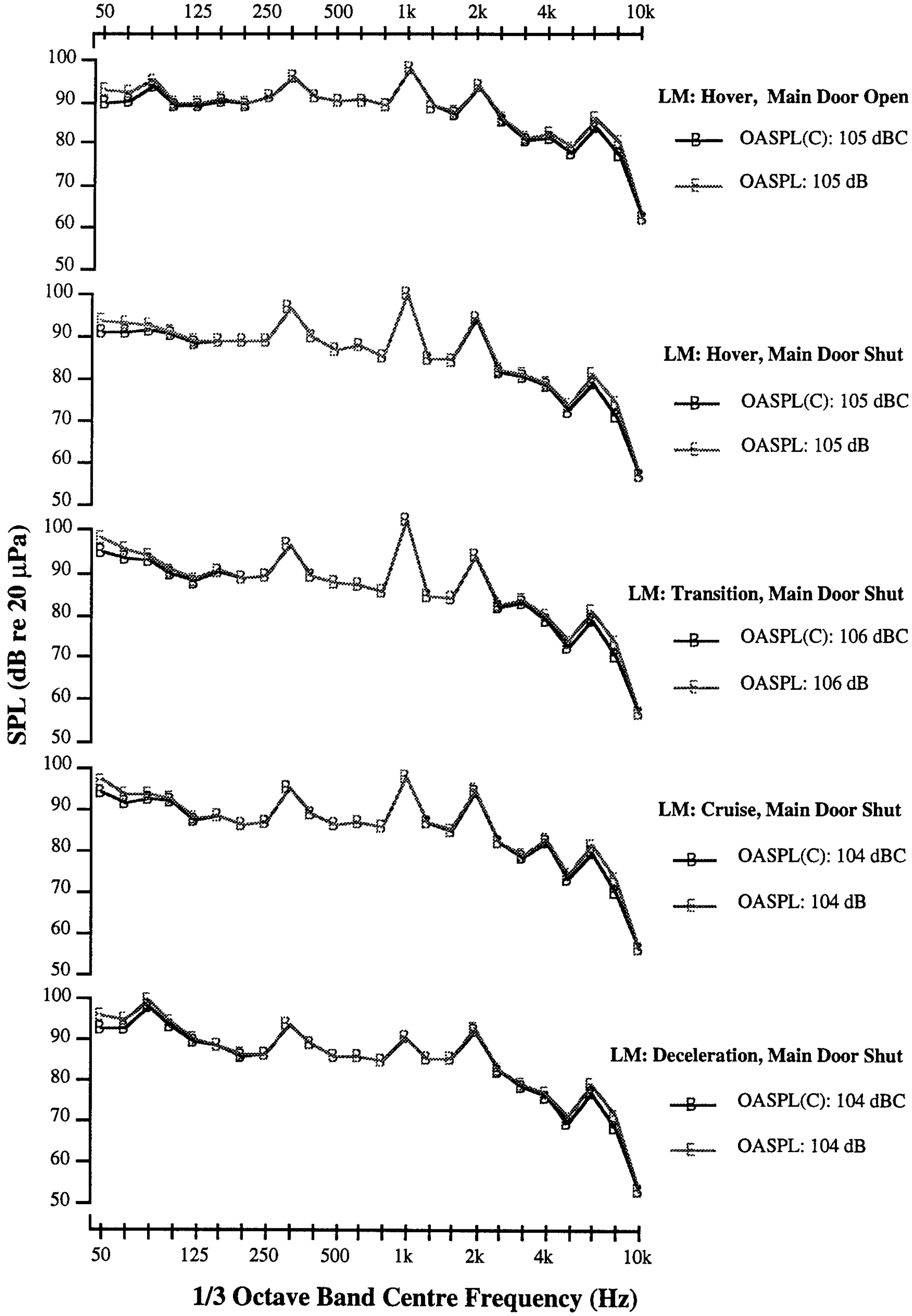
1/3 Octave Band Centre Frequency	Curve A dB	Curve C dB
50	-30.2	-1.3
63	-26.2	-0.8
80	-22.5	-0.5
100	-19.1	-0.3
125	-16.1	-0.2
160	-13.4	-0.1
200	-10.9	0
250	-8.6	0
315	-6.6	0
400	-4.8	0
500	-3.2	0
630	-1.9	0
800	-0.8	0
1000	0	0
1250	0.6	0
1600	1.0	-0.1
2000	1.2	-0.2
2500	1.3	-0.3
3150	1.2	-0.5
4000	1.0	-0.8
5000	0.5	-1.3
6300	-0.1	-2.0
8000	-1.1	-3.0
10000	-2.5	-4.4

APPENDIX B

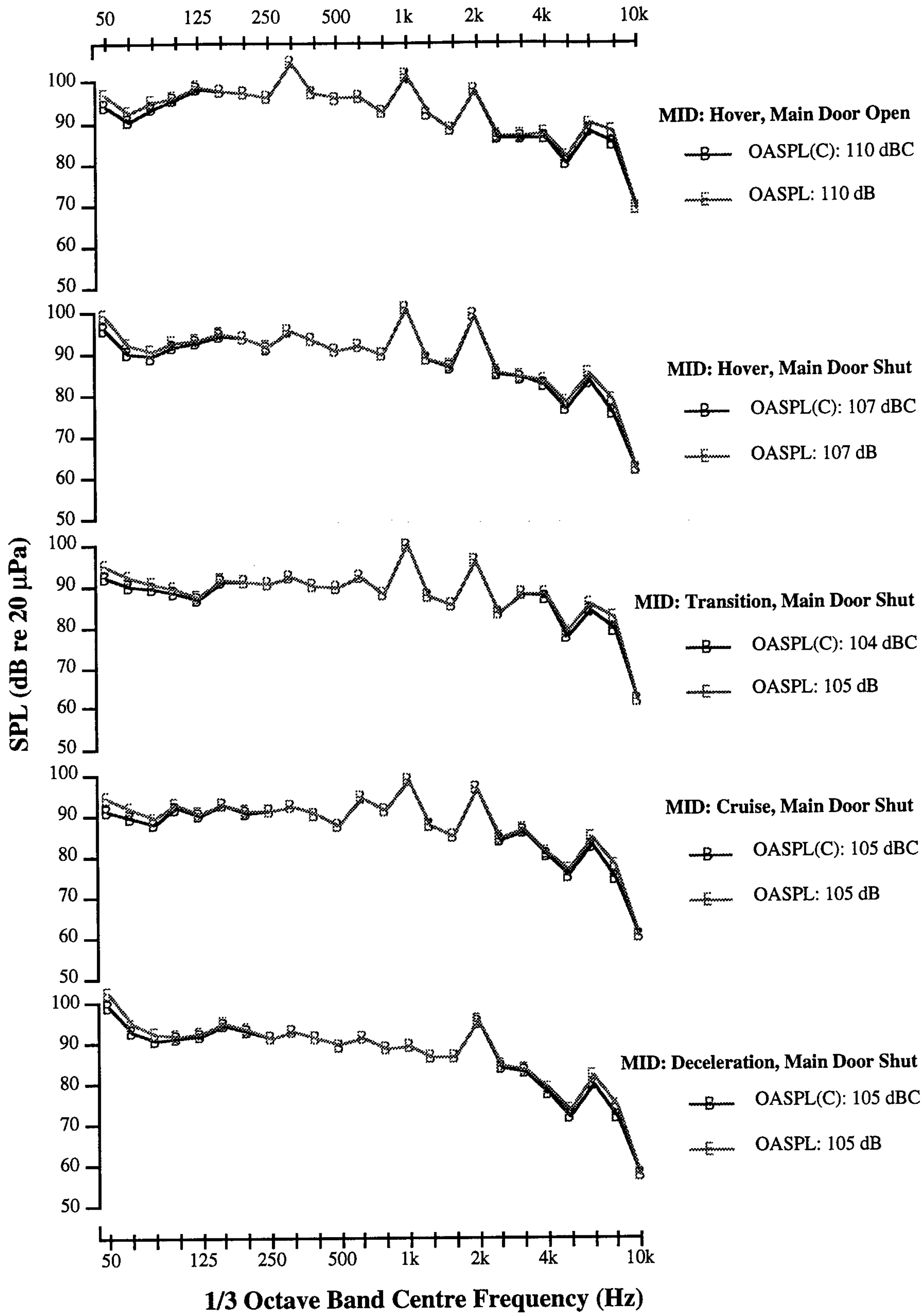
Third-octave analyses of the cabin noise measured at the Pilot, Loadmaster, Middle and Rear positions in each flight condition with Loadmaster windows closed



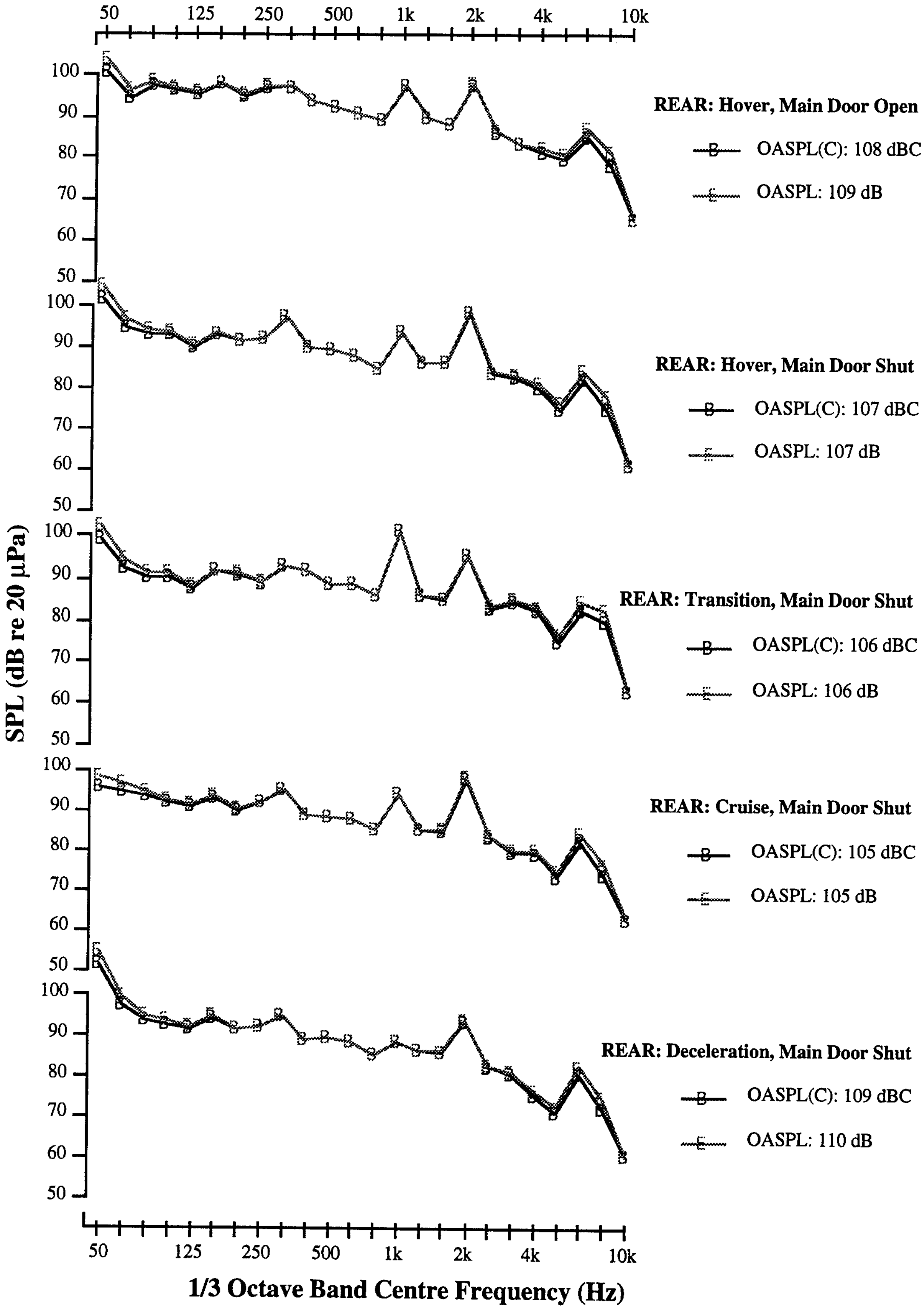
Third-octave analysis of the cabin noise measured at the Pilot position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were closed in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



Third-octave analysis of the cabin noise measured at the Loadmaster position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were closed in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



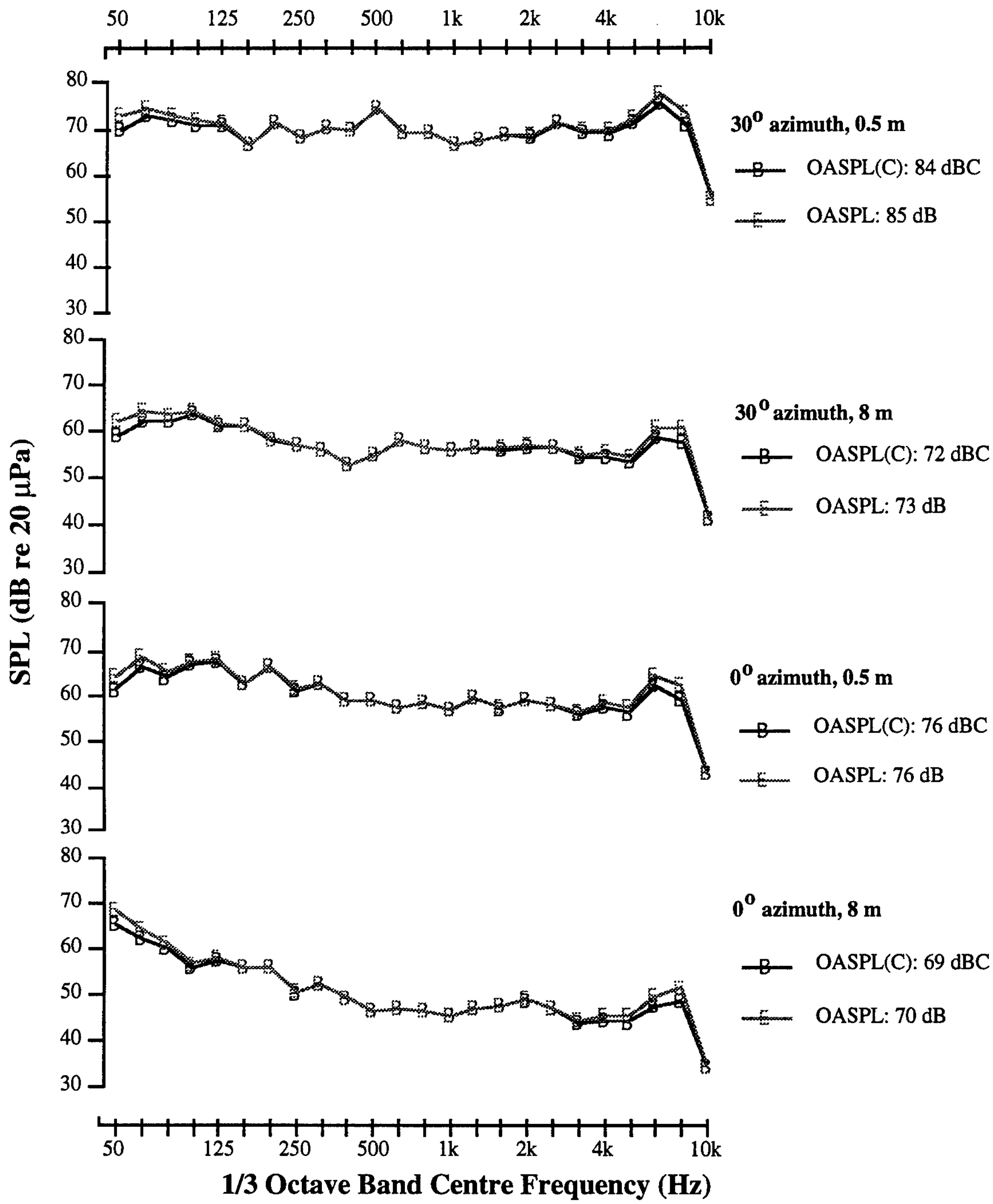
Third-octave analysis of the cabin noise measured at the Middle position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were closed in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



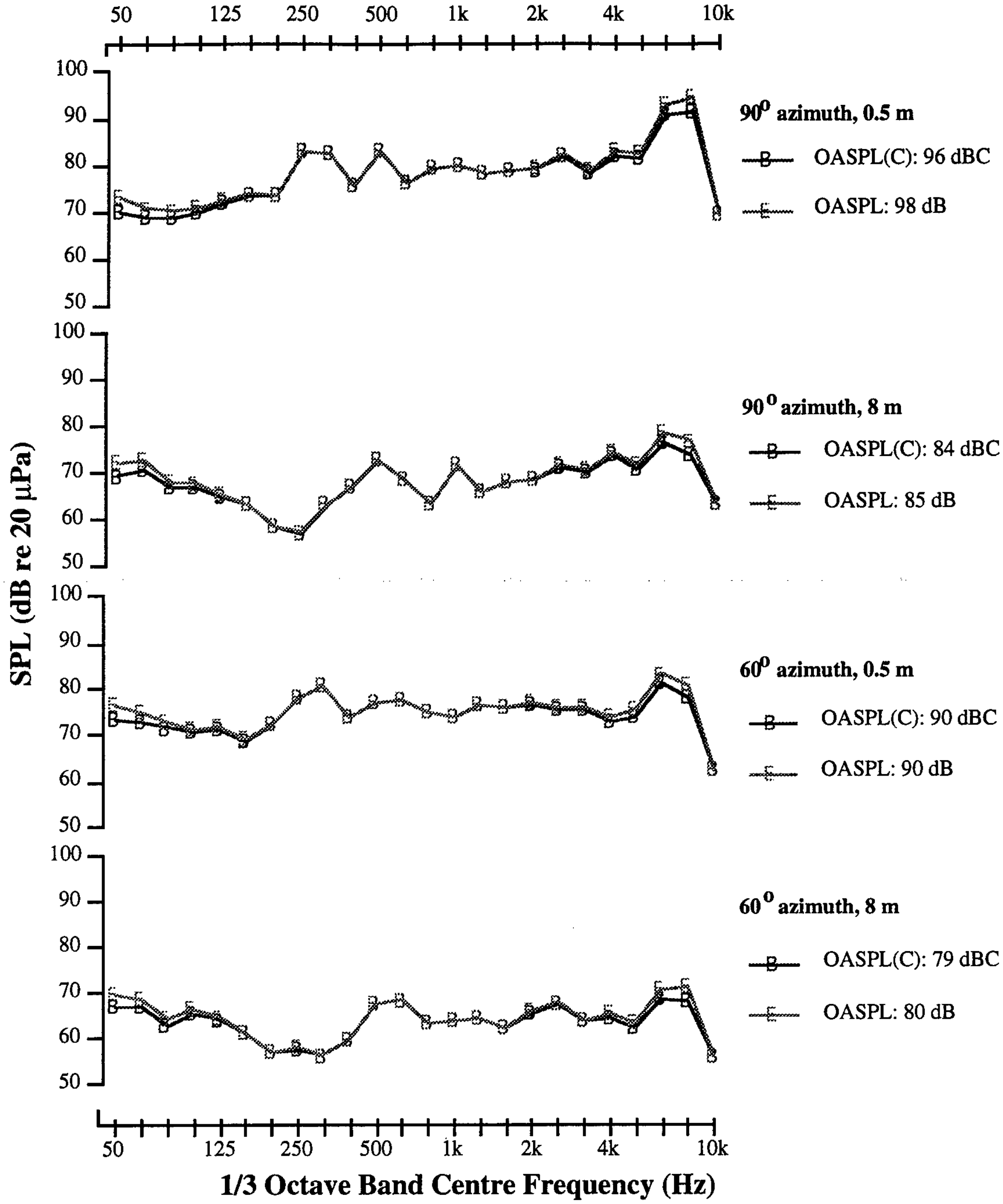
Third-octave analysis of the cabin noise measured at the Rear position in the Hover, Main Door Open; Hover, Main Door Shut; Transition, Main Door Shut; Cruise, Main Door Shut and Deceleration, Main Door Shut flight conditions. Loadmaster windows were closed in each case. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

APPENDIX C

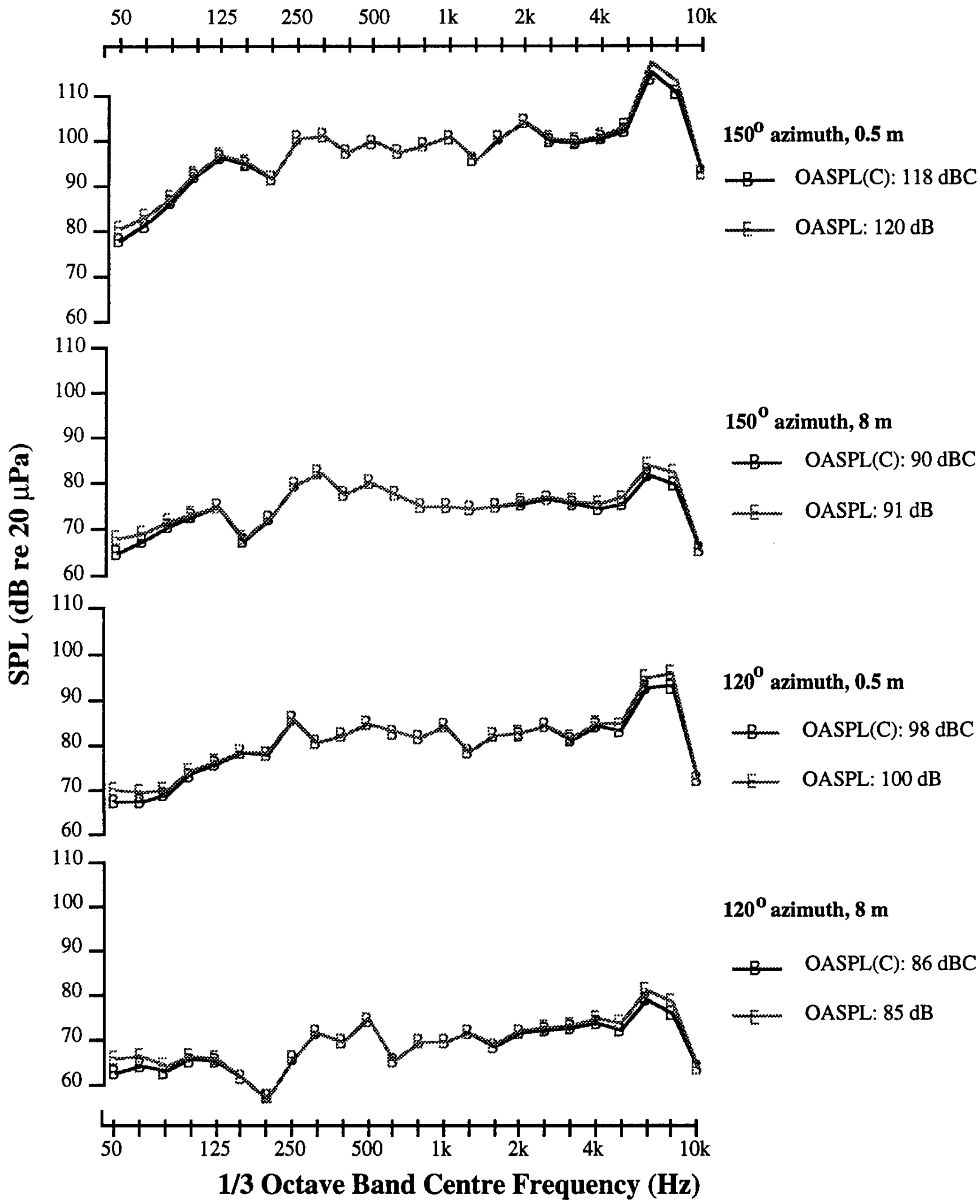
Third-octave analyses of the external noise 0.5 m and 8 m from the aircraft skin at all azimuth positions in each ground running condition



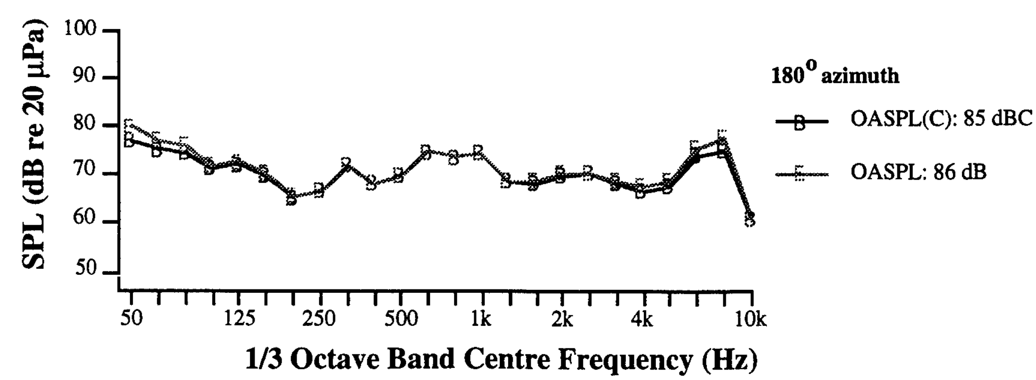
Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 0° and 30° azimuth positions with the auxiliary power unit running, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

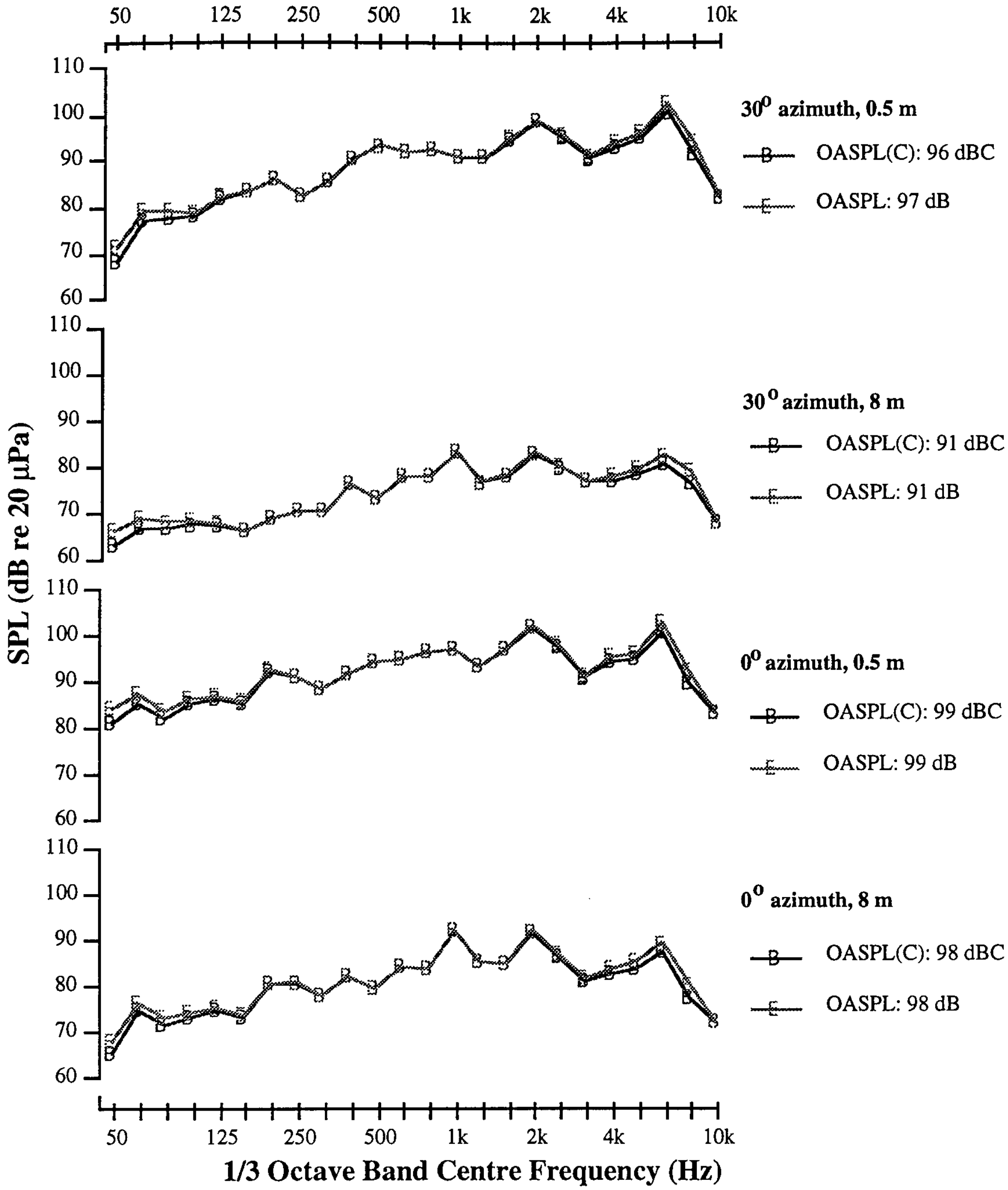


Above: *Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 60° and 90° azimuth positions with the auxiliary power unit running, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).*

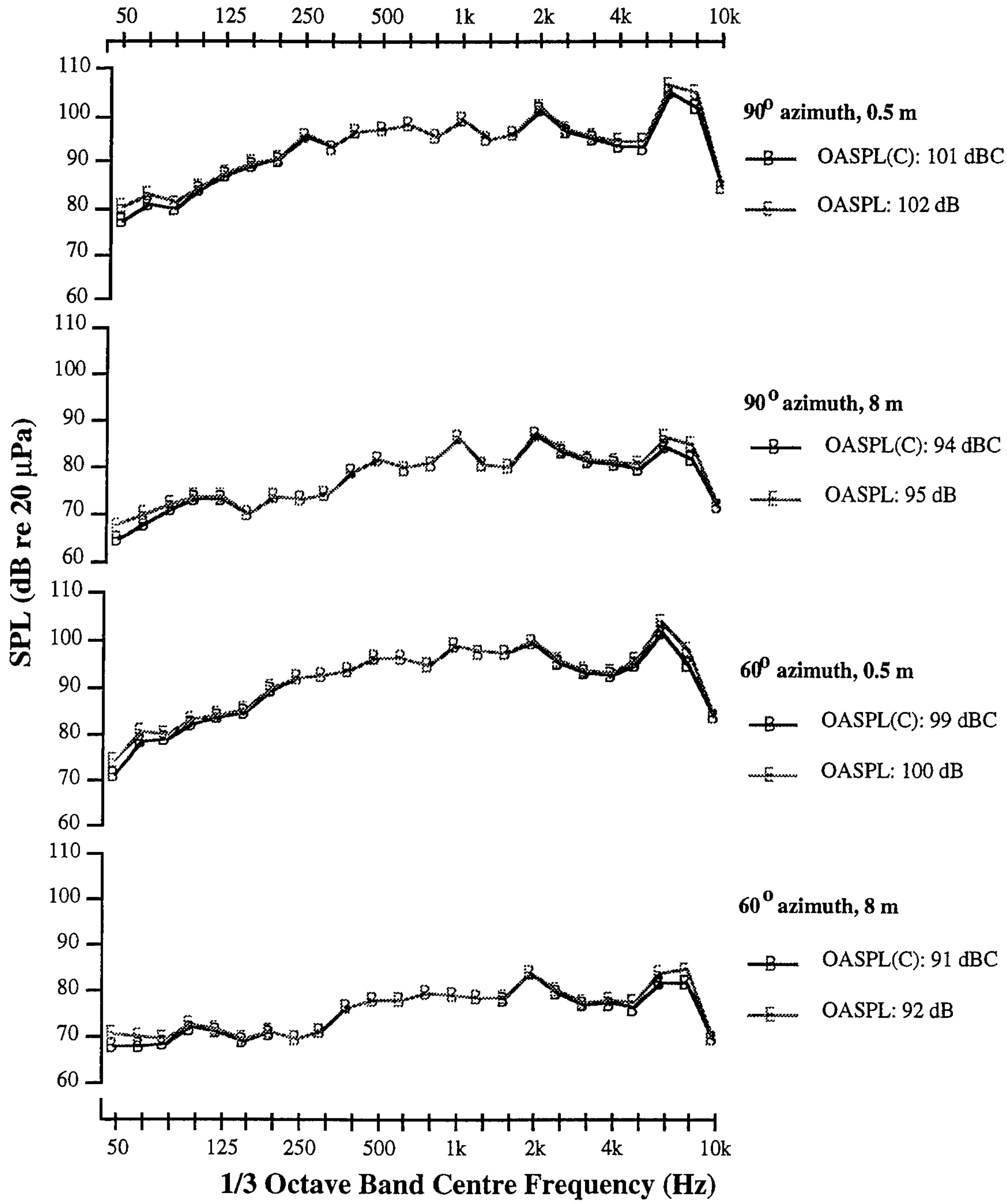


Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 120° and 150° azimuth positions with the auxiliary power unit running, aircraft on the ground. Below: Third actave analysis of the noise at the 180° azimuth position 3 m behind the tail rotor. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

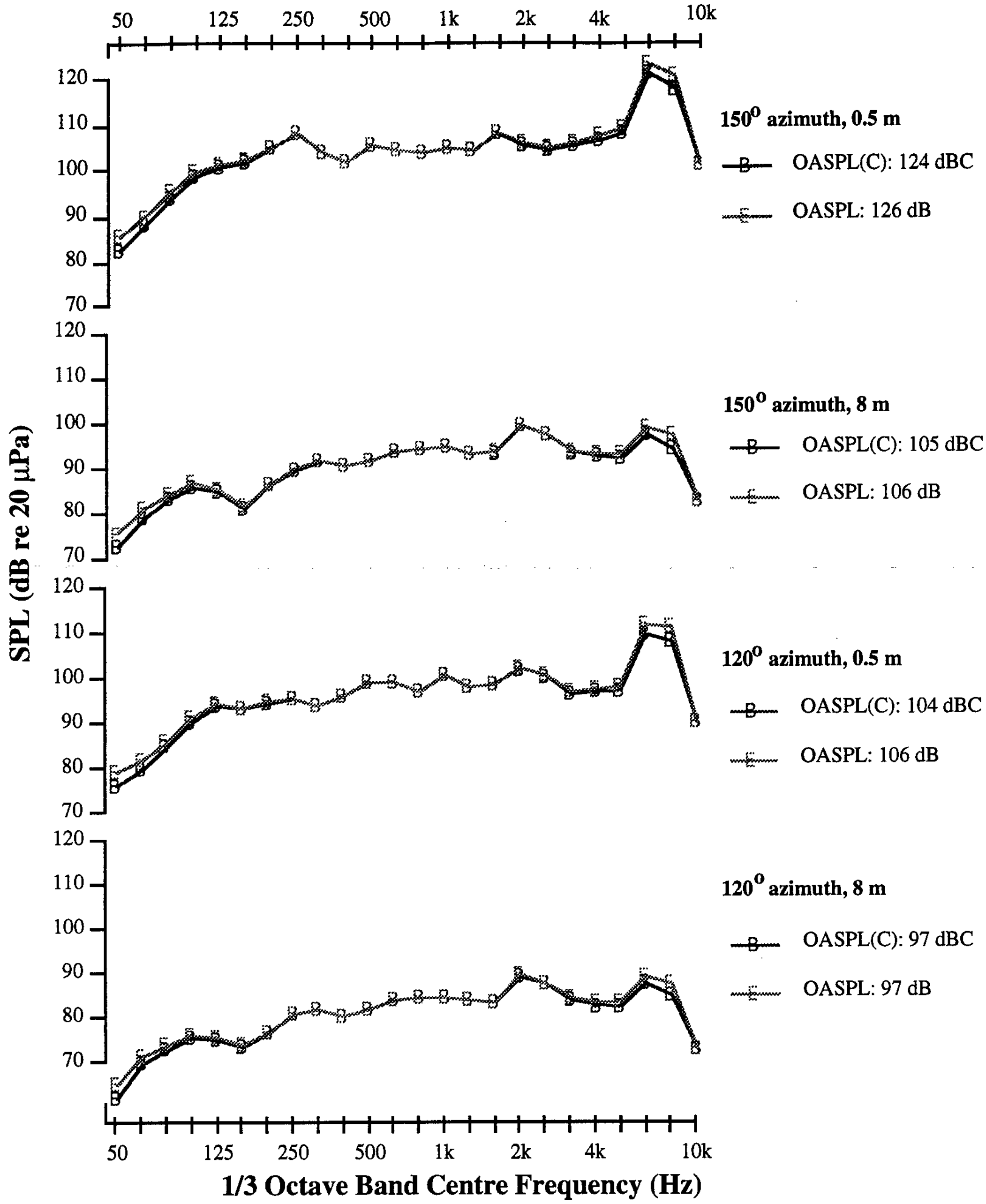




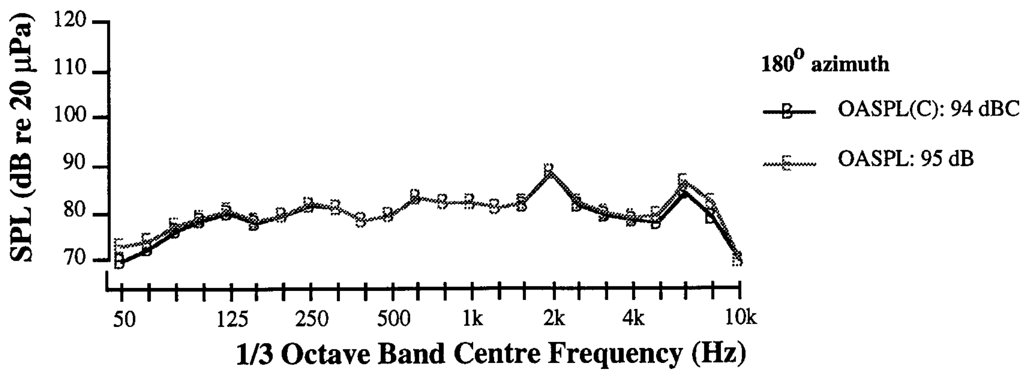
Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 0° and 30° azimuth positions with the auxiliary power unit and both turbines running, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

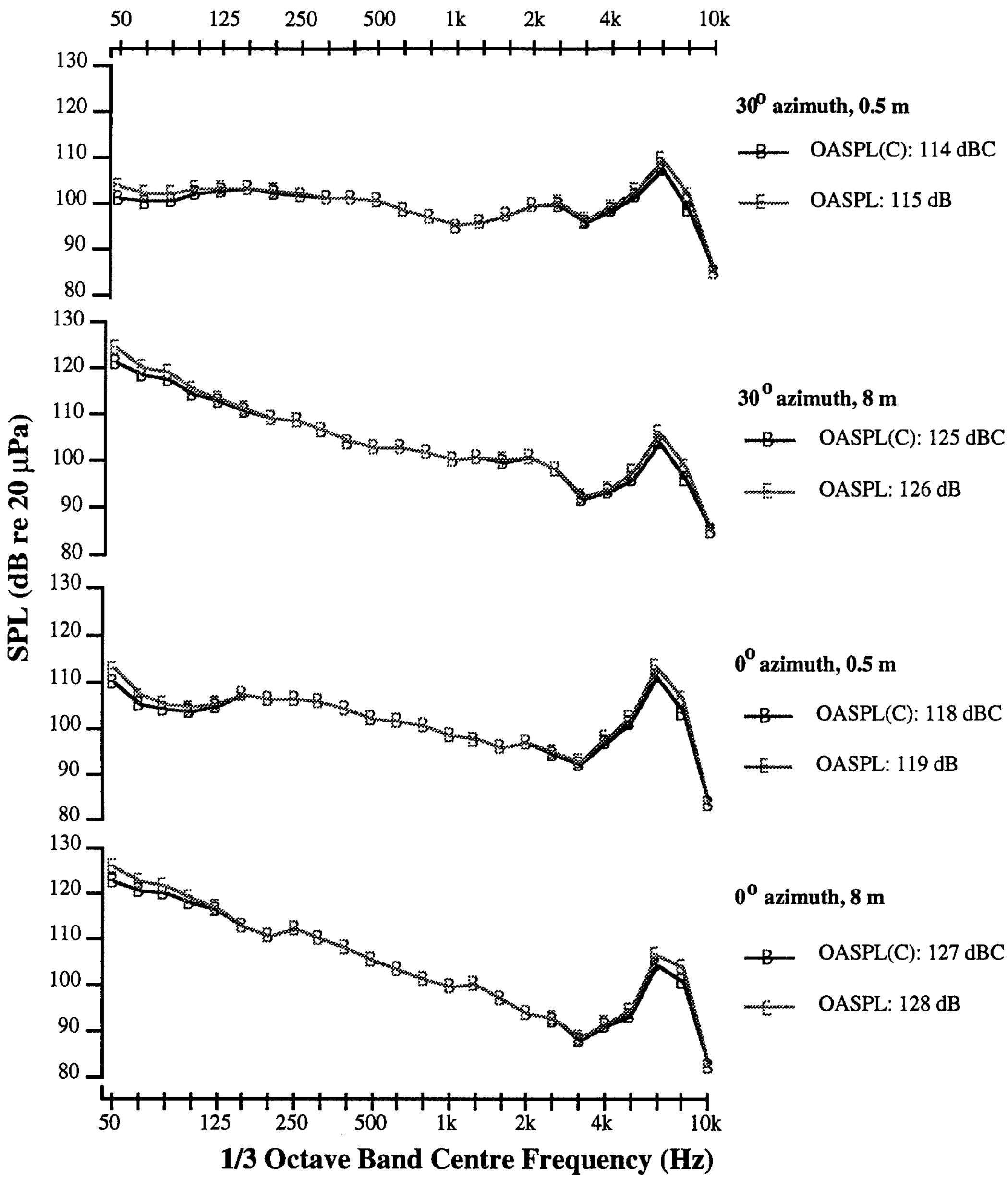


Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 60° and 90° azimuth positions with the auxiliary power unit and both turbines running, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

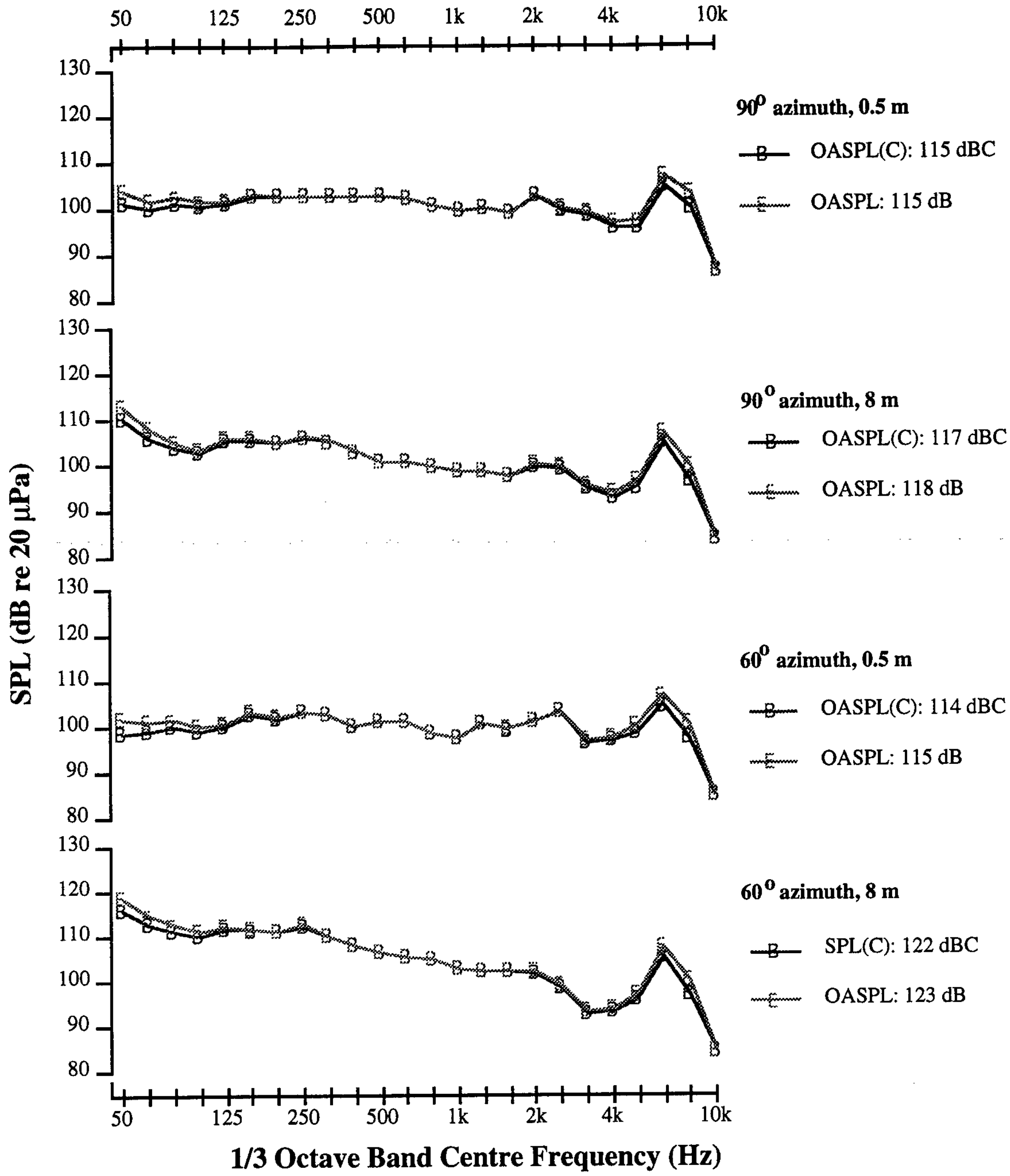


Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 120° and 150° azimuth positions with the auxiliary power unit and both turbines running, aircraft on the ground. Below: Third-octave analysis of the noise at the 180° azimuth position 3 m behind the tail rotor. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).

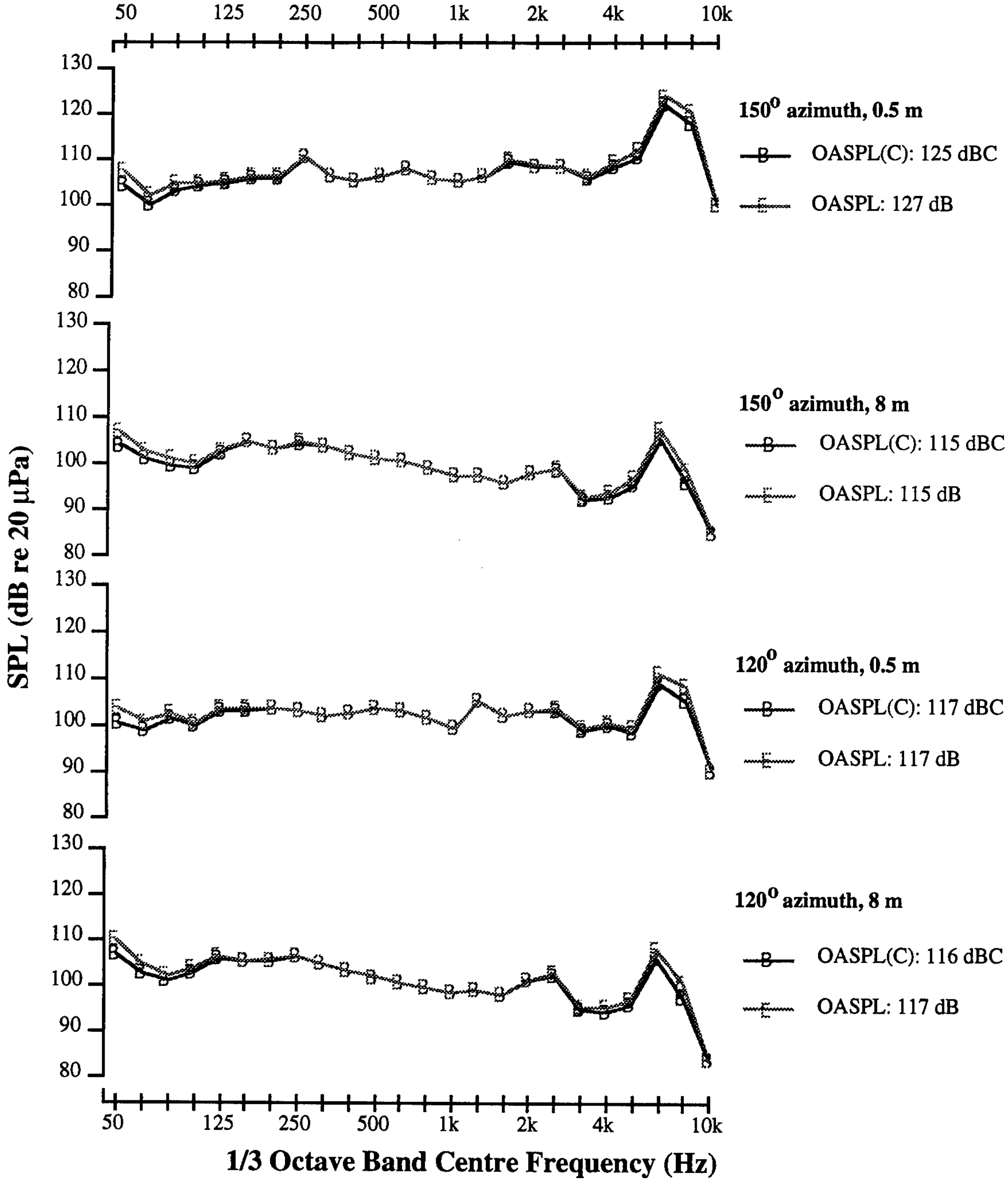




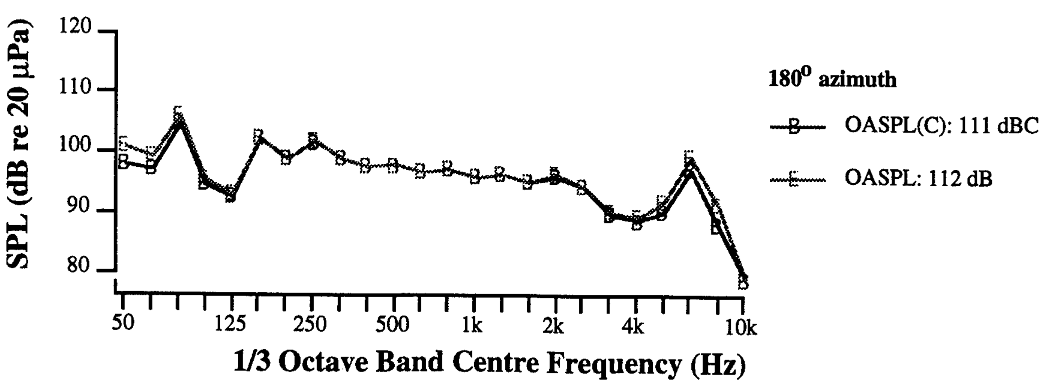
Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 0° and 30° azimuth positions with the auxiliary power unit running, both turbines at ground idle with rotors turning, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 60° and 90° azimuth positions with the auxiliary power unit running, both engines at ground idle with rotors turning, aircraft on the ground. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



Above: Third-octave analysis of the external noise 0.5 m and 8 m from the aircraft skin at the 120° and 150° azimuth positions with the auxiliary power unit running, both turbines at ground idle and rotors turning, aircraft on the ground. Below: Third-octave analysis of the noise at the 180° azimuth position 3 m behind the tail rotor. Also shown are C-weighted and unweighted Overall Sound Pressure Levels (OASPLs).



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20. ABSTRACT

This document reports the results of a comprehensive noise survey of the Sikorsky S-70A-9 Black Hawk helicopter environment and provides an assessment of the hearing protection devices worn by personnel exposed to this environment. Ambient noise levels were measured in the cabin of the Black Hawk at four positions under various flight conditions and at thirteen positions outside the Black Hawk under various ground running conditions. The attenuation properties of the ALPHA helmet, the Roanwell MX-2507 Communications Headset and the EAR earplug were also assessed. Results show that these devices do not always provide enough hearing protection to meet current conservation regulations (DIG PERS 19-4), even when worn in combination. Recommendations relating to the use of these hearing protection devices and the maximum Permissible Daily Exposure Duration (PDED) for personnel exposed to the Black Hawk environment are made.

Assessment of Noise Levels In and Around the Sikorsky S-70A-9
Black Hawk Helicopter

R.B. King, A.J. Saliba, D.C. Creed and J.R. Brock

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